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Relationships between personal social networks and spatial mobility with mobile phone data

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UNIVERSITY OF TARTU
Press

Department of Geography, Institute of Ecology and Earth Sciences, Faculty of Science and Technology, University of Tartu, Estonia

Dissertation was accepted for the commencement of the degree of *Doctor philosophiae* in human geography and regional planning at the University of Tartu on November 8th, 2021 by the Scientific Council of the Institute of Ecology and Earth Sciences of the University of Tartu.

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Commencement: Senate Hall, University of Tartu, Ülikooli 18,
on January 14th, 2022 at 14:15.

Publication of this thesis is granted by the Institute of Ecology and Earth Sciences, University of Tartu

ISSN 1406-1295
ISBN 978-9949-03-781-0 (print)
ISBN 978-9949-03-782-7 (pdf)

University of Tartu Press
www.tyk.ee

To my “core network” – my family

CONTENTS

LIST OF PUBLICATIONS

This dissertation is based on three publications that have been published in international peer-reviewed journals. Publications are referred to in the dissertation by their respective Roman numbers.

I **Puura, A.**, Silm, S., Ahas, R. (2018) The Relationship between Social Networks and Spatial Mobility: A Mobile-Phone-Based Study in Estonia. *Journal of Urban Technology*, 25(2), 7–25. https:/doi.org//10.1080/10630732.2017.1406253

II Silm, S., Mooses, V., **Puura, A.**, Masso, A., Tominga, A., Saluveer, E. (2021) The Relationship between Ethno-Linguistic Composition of Social Networks and Activity Space: A study using mobile phone data. *Social Inclusion*, 9(2), 192–207. https:/doi.org//10.17645/si.v9i2.3839

III **Puura, A.**, Silm, S., Masso, A. (2022) Identifying Relationships between Personal Social Networks and Spatial Mobility: A Study Using Smartphone Tracing and Related Survey. *Social Networks*, 68, 306–317. https:/doi.org//10.1016/j.socnet.2021.08.008

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Author's contribution to the papers: '*' denotes a minor contribution, '**' denotes a moderate contribution, '***' denotes a major contribution

	I	II	III
Original idea	**	*	**
Study design	**	*	**
Data processing and analysis	***	*	***
Interpretation of the results	***	**	***
Writing the manuscript	***	**	***

1. INTRODUCTION

Complex societal structures have always existed. However, developments in information and communications technology (ICT), as well as in transportation, have transformed communities into even more complex networks (Wellman, 2001). As networks have become a dominant form of social organisation and everything seems to be organised around electronically-processed information networks, the term 'network society' is often used to describe this modern type of society (Castells, 2010). Network analysis is considered as being vital to twenty-first century scientific investigation to gain a better understanding regarding all these rapid societal changes and complex processes (Watts, 2007). As a result, networks have increasingly been applied in the form both of theory and method in various fields of research, including the social sciences (Borgatti et al, 2009; Urry, 2003). However, the process of implementing networks is still somewhat lacking in some areas of research. To highlight the importance of networks in the field of human geography, in which mobility analysis is one of the main points of focus, this thesis will add a connection to that of personal social networks. Both personal social networks and spatial mobility are central to people's lives, being inextricably linked, and with a level of importance which has increased even further in recent decades (Axhausen, 2007). Individuals are increasingly more connected, carrying out their activities from a distance and on the move. As a result, activity-travel behaviour has changed significantly (Kwan, 2007; Sheller & Urry, 2006).

A continuous growth in research which serves to link together social networks and spatial mobility has taken off from the beginning of the twenty-first century (see e.g., Plaut & Schach-Pinsly, 2009). As a highly interdisciplinary field of research, these relationships have been explored through a number of field-specific approaches (such as transportation studies, sociology, physics, etc.). Activity-travel modelling approach has been one at the forefront, where personal networks and interactions in these networks are increasingly incorporated to model the activity-travel need (see e.g., Carrasco & Miller, 2006; van den Berg et al, 2012). The results of these analyses have shown that, when compared to personal characteristics, the distances to the members of this network and the composition of the network itself tend to be better predictors of social activity travel (Carrasco et al, 2008; Kowald et al, 2013). Significant additional knowledge has also been gained to understand socio-spatial isolation and accessibility, allowing an assessment to be carried out on the subject of inequalities (e.g., see Carrasco & Cid-Aguayo, 2012; Lee & Kwan, 2011). Some studies have also focused on other types of relationship while using a typological approach to understand the spatial distribution of personal social networks in relation to spatial mobility (see Cachia & Maya-Jariego, 2018). However, the use of such an approach is rather limited. All these studies have used traditional data collection methods, such as surveys, interviews, and travel diaries.

At the same time, major advancements are also being made in terms of network analysis with the use of ICT-based datasets. People's daily ICT-based communications and activities (such as the use of mobile phones and the internet) leave digital traces which can be successfully applied in the analysis of various societal phenomena (Masso et al, 2020). On the one hand, this data contains information about human interactions, but location-aware ICTs also store information about the spatial locations of the users (Blondel et al, 2015; Harrison et al, 2020). Mobile phone-based 'Call Detail Records' (abbreviated as CDRs) and social media data are some examples of these digital traces (Blondel et al, 2015; Grabowicz et al, 2014). Such data have been widely used in fields which are closely related to computational sciences (such as computer science or physics), making it possible to study general rules and trends in human socio-spatial behaviour (see Calabrese et al, 2011; Fan et al, 2017; Lazer et al, 2009; Shi et al, 2016). However, studies which connect these personal social networks with spatial mobility have tended to pay less attention to variabilities which have arisen either from personal characteristics or the locations of the daily activities of individuals (e.g., see Phithakkitnukoon et al, 2012). Studies which focus upon phone use intensity and spatial mobility have found that increased mobile phone use relates to more extensive spatial mobility, but is also influenced by these characteristics (see Yuan et al, 2012). So far, one important shortcoming is the lack of connections which are made between the knowledge gained from the use of ICT data and more traditional approaches to have a more in-depth understanding of these relationships. Therefore, despite the large number of studies which use ICT-based data, much remains to be discovered. As part of a highly interdisciplinary field, the broader goal of this thesis is to encourage collaboration between various disciplines, possibly establishing progress towards mapping out and understanding different social processes and problems through an analysis of networks.

The aim of this thesis is to provide new areas of knowledge regarding the relationships between personal social networks and spatial mobility, and those factors which serve to shape these relationships. The work is based on three articles in which these connections are studied through two types of mobile phone data: a) CDRs and call-graph data which are provided by mobile phone operators (MNOs) (**Articles I and II**); and b) data which have been collected through a smartphone application known as MobilityLog, along with related surveys (**Article III**). The studies cover various time periods between 2013–2017. The thesis therefore focuses on these connections prior to the beginning of the COVID-19 pandemic, looking at a time period in which people's daily activities did not abut potential restrictions which would limit both their physical communications and their spatial mobility.

While assessing the spatial extent and diversity both of personal networks of calling partners and spatial mobility, the following research questions are set out in the thesis:

1. What kind of relationships exist between the spatial distribution of personal social networks and spatial mobility? (**Articles I, III.**)
2. How do personal characteristics shape relationships between personal social networks and spatial mobility? (**Articles I, II, III.**)
3. How does ICT usage shape relationships between personal social networks and spatial mobility? (**Articles I, III.**)
4. How does network composition shape relationships between personal social networks and spatial mobility? (**Articles II, III.**)
5. How do the characteristics of daily activity districts shape relationships between personal social networks and spatial mobility? (**Articles I, II.**)

The thesis investigates these relationships within the Estonian context, while providing a thorough overview of the various characteristics which shape the connections between personal social networks and spatial mobility. Special attention is paid to networks and spatial mobility through the perspective of ethnic segregation, since the spatial behaviour of different ethnic groups is one of the most important shapers of inequality in Estonia (see Järv et al, 2015; Mooses et al, 2016; Mägi et al, 2016; Silm et al, 2018).

The importance of the topic and an overview of approaches used when it comes to studying these connections are further highlighted in the theoretical framework for this thesis. It incorporates knowledge gained from previously-conducted research in various disciplines. The methodological framework describes the data and methodologies used in those articles on which the thesis is based, while also providing a brief overview of the study area. The results chapter provides answers to the research questions which are presented. The discussion chapter outlines the key findings of this thesis by providing explanations of these results based on previous research, and gives directions for further research to understand these connections.

2. THEORETICAL FRAMEWORK

2.1 The two-way relationships between personal social networks and spatial mobility

Social networks are structures which are made up of a set of social actors and a set of ties between those actors (Borgatti et al, 2009). They can be studied through various approaches. Sociometry, which is a method which graphically measures relationships, had already been developed by the first half of the twentieth century when two psychotherapists, Moreno and Jennings, used the method to be able to observe the relationship between social structures and psychological well-being (see Moreno & Jennings, 1938; Moreno, 1941). The method has been used ever since then, quickly becoming essential in terms of being able to understand human society and how it is rebuilt by using human relationships as a basis.

Social actors may refer to individuals, but the term can also be used either for organisations, families, or even nations, etc, amongst which the relationships or 'ties' are measured (Borgatti et al, 2009). There are also a variety of ties which can be studied where, in social sciences, the most typical are based either on social relations, interactions, flows, or similarities which are found to explain a variety of social phenomena (Borgatti et al, 2009; Granovetter, 1973). Social networks can be viewed either from the perspective of a social actor (this being the 'ego-centric' focus), or by setting a focus on whole networks (Borgatti et al, 2009) (Figure 1). Ego-centric networks consist of all of the ties with other social actors ('alters') which arise from the 'ego' (Marin & Hampton, 2007). Sometimes the ties between alters are also considered during analyses of ego-centric networks to understand the structures which are inherent within these personal networks (in terms of its cohesion, for instance) (e.g., see Viry, 2012).

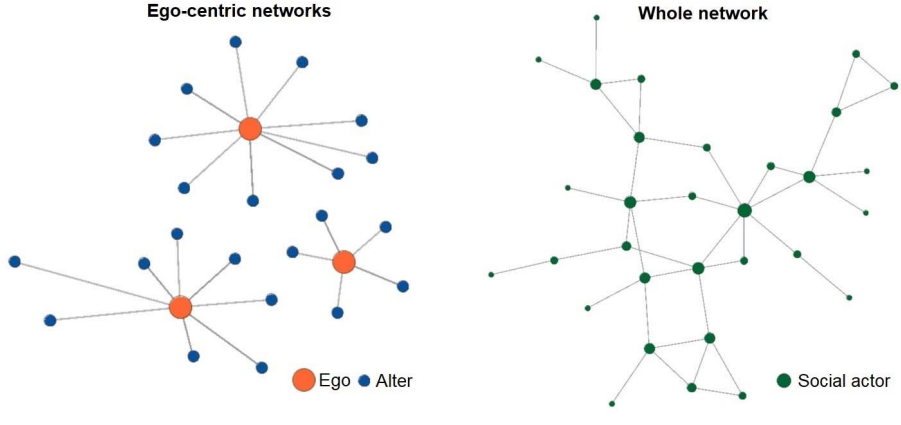

Figure 1. The ego-centric and whole network approach.

The whole network approach considers all the relationships between the social actors within the social organisation (such as in a school class, or within a company organisation). It enables the inclusion of a variety of measures which are related to the structure (such as centrality and density), which are needed to understand phenomena such as group formation, social influence, or the spread of viruses (Borgatti et al, 2009; Wellman, 1988).

Personal social relationships are often divided by the strengths which lie in these interpersonal ties (Borgatti et al, 2009; Marin & Hampton, 2007). The strengths of the ties are often measured in specific ways such as, for example, through mutually dedicated time and interactions, emotional intensity and who is considered to be socially 'close', and with whom reciprocal services and support are being shared (Granovetter, 1973; Marin & Hampton, 2007). The current thesis focuses on personal ego-centric networks, with these being based upon interactions between individuals. Interactions are the basis of relationships. They are required both to being able to create and also to maintain various personal relationships (Grossetti, 2005). As time is a limited resource when it comes to interactions with others (Miritello et al, 2013), the sizes of personal social networks tend to be limited (Hill & Dunbar, 2013), often consisting of layered structures. In these, a disproportionate amount of time and a number of interactions are devoted to a small number of closely-related partners which form the 'core network', followed by other layers of increasingly weaker relationships with lower levels of interaction (Carron et al, 2016; Dunbar et al, 2015; Dunbar, 2016; Roberts & Dunbar, 2011). This thesis also considers the types of social relationships. Studies of traditional personal social networks are often composed by others who are related to an individual via their roles (such as in terms of familial links or as friends, neighbours, or colleagues) (Borgatti et al, 2009; Marin & Hampton, 2007).

Personal social networks are directly linked to the placement of individuals in any physical space (Hägerstrand et al, 1970; Grossetti, 2005). Here, activity space is a concept which is used to describe the space-time behaviour of an individual. It consists of different activity locations to which a person has direct contact over the duration of those periods of time which are being considered, together with movements between and around these locations (Dijst, 1999; Golledge & Stimson, 1997). These activity locations can be divided into places which are visited regularly, less regularly, or randomly, with the most regular visits being referred to as 'anchor points' (Ahas et al, 2010). Due to the space-time constraints which are set out in terms of an individual's behaviour (Hägerstrand, 1970), the most important locations – such as place of residence or workplace – which are related to an individual's frequent daily activities generally serve to determine the extent and geography of the activity space, around which the daily life is concentrated and in which a considerable amount of time is spent (Flamm & Kaufmann, 2006; Schönfelder & Axhausen, 2010). The part of the activity space which is used every day is also known as the 'daily activity space' (Järv et al, 2015), or the 'usual environment' in tourism and statistical terms (OECD, 2016; Eurostat, 2016). In this thesis, spatial mobility has been treated as physical movement between various activity locations. The extent of spatial mobility depends significantly upon the

length of the study period, with more extensive mobility being more visible over longer periods of time, and consisting of longer leisure episodes and more freedom to travel over distance (e.g., see Järv et al, 2015).

All of these visible geographical constraints which are set out for individual behaviour are consistent with the 'First Law of Geography', as stated by Waldo Tobler (1970, p 236): 'Everything is related to everything else, but near things are more related than distant things'. The same phenomenon is known in social theory as the 'propinquity effect' which refers to the tendency to form relationships with others who are physically and psychologically more proximate (Festinger et al, 1950). The 'distance decay' effect tends to apply both to the spatial behaviour of an individual as well as social interactions and relationships which are formed. Activity locations tend to be located near the close vicinity of place of residence, and the number of places which are visited decreases when the distance from that place of residence increases (Golledge & Stimson, 1997; Schönfelder & Axhausen, 2010). Similarly, the number of interactions and the level of tie probability also decrease as physical distance increases (Deville et al, 2016; Lambiotte et al, 2008; Onnela et al, 2011), leading to fewer network members who live farther away from the place of residence (Calabrese et al, 2011; Kowald et al, 2013; Preciado et al, 2012).

The relationship between personal social networks and an individual's spatial mobility must be seen as a two-way process (Figure 2). Primary relationships stem from the family and from interactions in other daily activity locations such as schools, workplaces, or free time activity locations, all of which create the preconditions for further networking through physical exposure (Festinger et al, 1950; Grossetti, 2005). More connections are found to exist between people who are exposed to each other in shared locations (Bossard, 1932; Latane et al, 1995; Shi et al, 2016), and who have more overlapping activity spaces (Wang et al, 2015). The second direction is represented by the need for individuals to undertake spatial mobility activities to be able meet members of their personal social network with whom social activities are conducted (Calabrese et al, 2011; Carrasco & Miller, 2006; van den Berg et al, 2012). To ensure the functioning and maintenance of different relationships and mutual well-being, face-to-face meetings with a certain level of regularity are required within specific times and in specific places (Urry, 2003; Yousuf & Backer, 2015). The geographical distribution of the networks is therefore found to be crucial (e.g., see Carrasco & Miller, 2006; Carrasco et al, 2008; Guidon et al, 2018; Kowald et al, 2013). Long-distance relationships require more travelling by at least one of those parties which form part of these relationships (Calabrese et al, 2011). Even more, long-distance travel rather short-distance travel is found to be more highly connected to the spatial distribution of personal social networks (Cho et al, 2011).

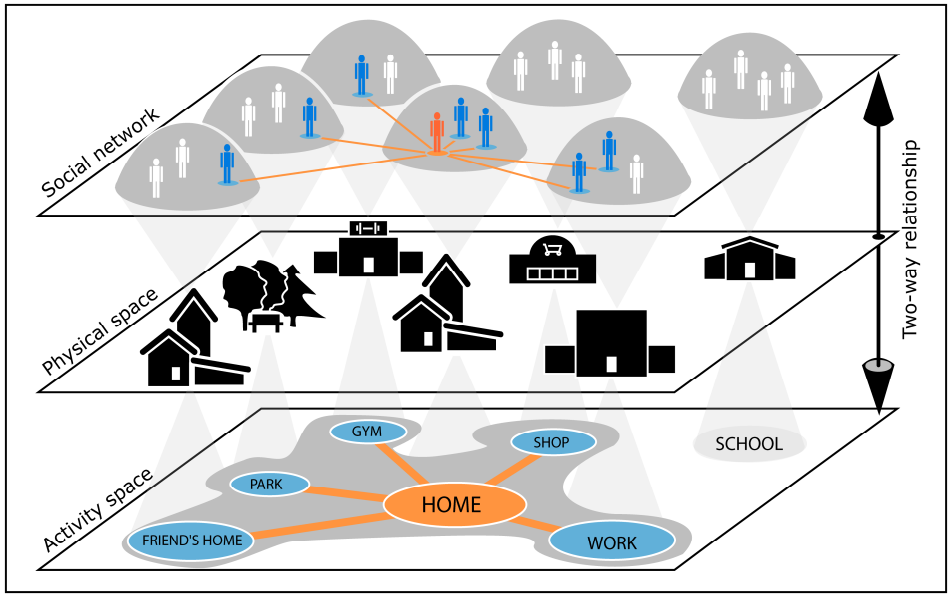

Figure 2. Two-way relationship between an individual's social network and activity space. Source: **Article II** (Silm et al, 2021).

Although not the focus of the current thesis, both personal social networks and activity spaces are not constant or fixed, but are instead dynamic. They constantly change and co-evolve over time. The most important changes in the spatial distribution of personal networks and activity spaces have been found in relation to migration, which often results in increased distances between people and different activity locations, and which leads to more geographically-extensive networks and mobility (Fudolig et al, 2021; Kamenjuk et al, 2017; Levy, 2010; Sharmeen et al, 2015; Viry, 2012). Over the years, the geographical extent of personal networks has increased together with the extent of individual activity spaces (Axhausen, 2007; Danchev & Porter, 2018). Relocations are also found to be related to the turnover of members in personal social networks (Saramäki et al, 2014), in which it is mainly the strongest relationships which are successfully maintained (Carrasco et al, 2008). Knowledge about residential relocation and changes in other activity locations are both therefore important when it comes to being able to understand the dynamics in networks and further travel needs (Sharmeen et al, 2015). The permanence of relocating is also important, with more permanent relocations tending to be related to the development of more local networks, while short-term stays are related to keeping hold of networks in one's place of origin (Cachia & Maya-Jariego, 2018).

Not all individuals are as mobile regarding their personal social networks, since some individuals tend to be more mobile than their peers (Calabrese et al, 2011). Limited physical mobility can sometimes be related to higher levels of physical restriction (Dekker et al, 2015), or social exclusion (Schönfelder & Axhausen, 2003). To more fully understand these relationships between personal

networks and spatial mobility, information about other characteristics are required such as those which are related to individuals, their networks, ICT usage, and daily activity locations (e.g., see Daraganova et al, 2012; Sharmeen et al, 2015).

2.2 Personal characteristics which shape personal social networks and spatial mobility

Characteristics which are based upon individuals are amongst the widest-studied when it comes to attempting to explain differences in personal networks and spatial mobility, or the connection between the two. How people devote their time to different relationships, activities, and spatial mobility has been found to be related to a large number of personal characteristics, such as an individual's age and life stage (Wrzus et al, 2013; Carrasco & Miller, 2006), or their gender (Palchykov et al, 2012; Silm et al, 2013), their ethnicity (Järv et al, 2015; Silm et al, 2018), or their employment and socio-economic status (such as in terms of their occupation, education, and income) (Carrasco & Miller, 2006; Tillema et al, 2010; van den Berg et al, 2012).

Life stages and life cycle events introduce some of the most important differences into human social and spatial behaviour according to individual needs and the societal roles which individuals play (Bidart & Lavenu, 2005; Saramäki et al, 2014; Sharmeen et al, 2015). At a young age, choices regarding activity locations and interactions are strongly dependent upon the closest family members, a period which is followed by more independent life stages (Chakrabarti & Joh, 2019; Jiron & Carrasco, 2020; Wrzus et al, 2013). Personal social network size is found to increase until early adulthood and then start to decrease (Wrzus et al, 2013). Adolescents and children tend to have more friends, and have a higher frequency of social interaction in order to satisfy their informational goals while, at the start of adulthood, more attention is placed on closer relationships while seeking out the fulfilment of emotional goals (David-Barrett et al, 2016; Tillema et al, 2010; Wrzus et al, 2013). Older people are found to face the highest levels of suffering from a risk of social isolation, with their social networks being crucial to ensure their quality of life (Kemperman et al, 2019). The effects of isolation are often amplified by the fact that older people tend to have spatially more distant networks (Viry et al, 2009), and the lowest mobility levels (Carrasco et al, 2008). However, Kowald et al (2013) found the effect between network distribution and age tends to vary by country. In terms of mobility, Masso et al (2019) found that the most active groups in older generations tended to conduct more activities beyond the borders of the country in which they resided.

Forming a partnership is a life event which serves to change the expectations which are placed on various social relationships. Single people have more friends with whom they more frequently communicate and interact, while couples tend more often to befriend other couples (Stadtfeld & Pentland, 2015; Tillema et al, 2010; van den Berg et al, 2012; Wrzus et al, 2013). Becoming a parent shifts

relationships and communications towards others with similarly-aged children, and family members thanks to a sense of connectedness through the shared life stage (Carrasco & Miller, 2006; Kowald et al, 2013; van den Berg et al, 2013). In terms of spatial mobility, both reducing and increasing the effects of parenthood can be presented as follows: on the one hand there is more time being spent on fostering parental responsibilities while, at the same time, the needs of close family members may lead to more travelling for their activities (Chakrabarti & Joh, 2019; Jiron & Carrasco, 2020). The loss of a spouse or other close relationships may lead to a decrease in the size of one's personal network and eventually the replacement of such relationships (Zettel & Rook, 2004).

During an individual's lifetime, personal social networks increase not only in terms of their size, but also in their geographical reach due to activities in various activity locations (Bidart & Lavenu, 2005; Cachia & Maya-Jariego, 2018; van Acker et al, 2010; Viry, 2012). When studying as part of one's higher education, socialising tends to increase along with spatial mobility (van den Berg et al, 2012; Carrasco & Miller, 2006). People who have a more privileged education, or a better occupational and economical status, have better access to networks which consist of a broader range of role-relationships and on a spatially larger scale, while also having a greater level of ability to be more mobile and to establish such relationships (Carrasco et al, 2008; Kamruzzaman & Hine, 2012; Kowald et al, 2013). Working during adulthood may similarly lead to more spatially-distributed and more diverse activity spaces (Masso et al, 2019), either due to the distances between home and workplace (Yuan et al, 2012) or to the requirements for travelling due to the occupation in question (Aguiléra & Proulhac, 2015). Requirements which are related to studying or to work, are in turn also more likely to be connected to seeing less of friends (Tillema et al, 2010). When work colleagues form an important part of one's personal social network during one's working life (van den Berg et al, 2012; Tillema et al, 2010; Wrzus et al, 2013), retirement and disengagement from work tends to lead to one's colleague-related network shrinking markedly (Cozijnsen et al, 2010). With that said, over the years retirement has become less of a disruptive event, and some of the more intrinsically rewarding work-related relationships continue to be important (Cozijnsen et al, 2010).

Women are found to have personal social networks which consist of a higher proportion and greater diversity of familial ties (Moore, 1990). Their network members tend to be more concentrated near homes when the figures are compared to networks for men (Kowald et al, 2013). How parenthood affects networking and mobility is also connected to gender inequalities, where women tend to take on more of the child-rearing responsibilities (Palchykov et al, 2012). In mobility studies, women are found to have smaller numbers of out-of-home social interactions and activities (Carrasco & Miller, 2006; van den Berg et al, 2012; Yuan et al, 2012), which is also reflected in their lower levels of spatial mobility and the smaller extent of their activity spaces when compared to those of men (Hamilton, 2001; Polk, 1996; Silm et al, 2013). The high mobility levels for men

can also often be seen to be related to their better access and ability to use a car (Chakrabarti & Joh, 2019; Cristaldi, 2005; Silm et al, 2013).

Other examples of restrictions which are set for individual spatial behaviour relate to the ethnic background of individuals, where ethnic minority groups are often differentiate by lower levels of spatial mobility and a lower number of visited locations at the domestic level (Järv et al, 2015; Silm & Ahas, 2014). In turn, they may tend to undergo more cross-border trips (e.g., see Mooses et al, 2020). Personal social networks and mobility are also affected by other personal characteristics. Although it is not the focus of this thesis, personality traits influence the need to be socially and spatially active. For example, extroverts are inclined to have more enthusiastic attitudes when it comes to promoting exploration and diverse routines, while neuroticism is related to openness in evolving routines over longer periods of time (Alessandretti et al, 2018).

2.3 The use of ICTs in spatial mobility and shaping personal social networks

As social interactions are made possible through mobile phones, social media, and other networking channels, this has somewhat lessened the constraints which had previously been set by physical space (Dekker et al, 2015; Schwanen & Kwan, 2008). This has contributed to the development of bigger and geographically more extensive networks (Castells, 1996; Castells, 2010; Gonzales, 2017; Larsen et al, 2006). With ICTs having been seen both to increase and decrease physical mobility (Aguiléra et al, 2012; Mokhtrian, 2009), this area is mainly found to be dependent upon the type of activity or form of travel which is being conducted, and on the types of ICT channels which are being used (Lee-Gosselin & Miranda-Moreno, 2009; Miranda-Moreno et al, 2012; Mokhtarian, 2009). In relation to social activities and travel, these areas have mainly been found to be stimulated or enhanced through the use of ICTs (Mokhtarian et al, 2006; Mascheroni, 2007; Tillema et al, 2010). However, the use of ICTs can also be influenced by existing 'digital divides' which are based on personal characteristics. For example, different generations tend to use ICTs in different ways in order to increase their capability when it comes to for networking (Wang & Law, 2007). It is more often younger people, rather then older, who tend to use ICTs in place of physical mobility (Masso et al, 2019).

Regarding personal relationship management, people tend to use ICTs to interact with others who are either physically closer or who have a closer relationship with them (Tillema et al, 2010; van den Berg et al, 2012). The geographical constraint is reflected by the distance decay effect which tends to exist not only in face-to-face networks but can also be measured based on interactions through mobile phones (Lambiotte et al, 2008; Onnela et al, 2011) or through social media (Lengyel et al, 2015; Takhteyev et al, 2012). There is also a significant overlap between these different networks, since these are necessary for communications

and the coordination of activities with personal networks over distance and on the move (Kwan, 2007; Larsen et al, 2008; Licoppe & Smoreda, 2005; Line et al, 2011). Limits still exist, though, in regard to online media which it is not able to overcome. Close personal relationships still require at least occasional face-to-face meetings and some form of physical co-presence (Dunbar, 2016).

The use of ICTs may differ in relation to the distances to network members, as well as based on the roles of those network members. ICT becomes more important and useful during times in which physical absence becomes obvious in terms of close relationships (Rainie & Wellman, 2012), and ICTs can find themselves being used more as substitutes for travel when distances increase between individuals (Cachia & Maya-Jariego, 2018; van den Berg et al, 2012). Distance also determines the length of individual communications over ICTs, as people make longer calls for communicative purposes with long-distance partners, while shorter coordinating calls are more common with others who are physically closer (Moyano et al, 2012). The choice between different tools and channels can also be found to be connected with the strength of the relationship. People use more mobile phones and instant messaging with family and friends (Ling, 2008; van den Berg et al, 2012), while the internet and social media tend to support networking and communications for weaker ties (Hampton & Wellman, 2003; Koban & Krüger, 2018).

The use of ICTs has been an important medium, allowing people to keep in contact with network members back in their country of origin (Cachia & Maya-Jariego, 2018). Even more, when majorities are found to create most of their relationships through face-to-face interactions, minorities are inclined to create them online, allowing them to overcome the effects of space (Gonzales, 2017). The use of social media has been found to support both interethnic and intra-ethnic contacts as it offers a new space in which interethnic contact can take place when it is created in venues which are organised around common interests. Intra-ethnic online communications, however, can also be related to struggles with identity and lifestyles which themselves are related to ethnicity (Dekker et al, 2015).

2.4 Network composition in spatial mobility and spatial distribution of networks

The term ‘composition of networks’ refers to the proportions of network members who have either similar or different characteristics (Bojanowski & Corten, 2014). Knowledge about composition is important when it comes to being able to understand the spatial distribution of personal social networks and their related spatial mobility (Carrasco & Miller, 2006; Tillema et al, 2010). For example, networks can consist of others who have concrete roles and tie strengths (Wellman et al, 1997). Where the composition of personal social networks has been studied, they have mainly been found to be family-centred, with relationships with family

members and the closest friends being found to be more stable and being maintained as the most durable ties (Degenne & Lebeaux, 2005; Fudolig et al, 2021; Marsen et al, 1997; Wellman et al, 1997). In turn, weaker relationships are found to be less stable and more affected by physical relocations, an act in which relationships with others, such as work colleagues, classmates, or neighbours are often replaced by new local-level relationships (Ryan, 2007; Saramäki et al, 2014; Visser et al, 2014). Moreover, the type and strength of relationships determine the activity locations in which socialisation occurs (van den Berg et al, 2012; Carrasco & Miller, 2006). Hosting and visiting occur when people have stronger relationships, while public places are more commonly used with weaker relationships, such as work colleagues (Carrasco & Miller, 2006).

The similarities in the composition of personal networks are closely related to the tendency to form relationships with people who are more similar to ourselves, a form of behaviour which is known as 'homophily' in social theory (Kossinets & Watts, 2009). This tends to lead to more homogeneous personal social networks which are based either on socio-demographics (such as race, ethnicity, age, gender, or socioeconomic status), or psychological characteristics (such as attitude, aspirations, or intelligence) (Kossinets & Watts, 2009; Marsden, 1987; McPherson et al, 2001). This leads to segregation in personal social networks, which is seen as the extent to which individuals tend to associate with others who have either the same or different characteristics (Bojanowski & Corten, 2014; Kossinets & Watts, 2009). These preferences are often justified in several ways such as, for example, by more effective communications, faster mutual understanding, and trust due to similar characteristics between the individuals (DiPrete et al, 2011; Kossinets & Watts, 2009; McPherson et al, 2001).

Language and cultural similarities are one of the most important factors when it comes to seeing what serves to form individual activity spaces in terms of scope (Boterman & Musterd, 2016; Silm & Ahas, 2014), and ethno-linguistic composition in those areas which are visited (Silm & Ahas, 2014; Yip et al, 2016). For example, within the context of Estonia, the country's Russian-speaking minority tends to have smaller activity spaces and less visited locations, with those locations being concentrated more towards areas in which the proportion of people who are of the same ethno-linguistic group is higher (Järv et al, 2015; Silm et al, 2018; Wong & Shaw, 2011). In terms of transnational activity, Russian-speakers in Estonia tend to be more mobile, and tend to visit their ancestral homeland where they can find a similar linguistic context (Mooses et al, 2020). The clear effect of language barriers and functional relationships between regions are similarly visible when use is made of community detection methods, where some administrative units have stronger connections according to call activity records (Expert et al, 2011; Ratti et al, 2010).

Different forms of relationship, both strong and weak, must be seen as forms of social capital as they provide access to information, resources, and also to activity locations (Bourdieu, 1986; Hägerstrand, 1970; Kossinets & Watts, 2009). An understanding of these networks is required to explain, for example, unequal access to jobs and the distribution of other forms of resources, which tends to lead

some people towards poorer living conditions and even poverty, and which can be used to understand the imperfect participation within society of oppressed groups (Kwan, 2013; Lee & Kwan, 2011; Marques, 2012; Wissinik et al, 2016). Having diverse social relationships of different strengths and affiliations, in turn, has been directly linked to a person's economic success, quality of life, and professional achievements (Burt, 1996; DiMaggio & Garip, 2012; Eagle et al, 2010; Granovetter, 1973). In relation to ethnicity, these personal relationships and networks can, for example, be found to serve to enhance and mitigate the effects of isolation where it is produced by space (DiMaggio & Garip, 2012; Marques, 2012).

2.5 The characteristics of daily activity districts which shape personal social networks and spatial mobility

One's place of residence and workplace are related to an individual's most frequent daily activities, with the two together forming the centre of one's individual activity space (Dijst, 1999; Schönfelder & Axhausen, 2010). The characteristics of home and workplace locations can therefore be decisive in terms of exposure to other individuals and access to different activity locations and services. Individuals must always be seen to be placed within certain contexts to be fully able to understand the space-time and social constraints which are set against their behaviour, while determining both personal relationships which are formed and the need for spatial mobility (Farber & Li, 2013; Hägerstrand, 1970; Kwan & Schwanen, 2016; Small & Adler, 2019). Access to activity locations and exposure to others tends to vary across areas which have different population density levels, with denser areas and more attractive and multifunctional areas tending to encourage one to be active at the local level closer to one's own home (Meurs & Haaijer, 2001; Neutens et al, 2013; Scheiner & Kasper, 2003; Viry, 2012). Densely populated areas such as bigger cities are found to produce more spatially concentrated activity locations and networks (Phithakkitnukoon et al, 2012).

On the other hand, more sparse areas with longer distances between activity locations may lead to more mobile lifestyles and forced mobility (Meurs & Haaijer, 2001; Scheiner & Kasper, 2003; de Vos & Witlox, 2016; Yuan et al, 2012). Greater distances between home and workplaces can also be related to greater spatial mobility, as individuals have to travel more frequently or over longer distances between these places (Yuan et al, 2012). A well-developed infrastructure enables individuals to move further afield and to be connected to others on a broader spatial scale, while also being able to establish and maintain long-distance personal networks (Kamruzzaman & Hine, 2012; Kowald et al, 2013; Matous et al, 2013; Rainie & Wellman, 2012; Viry, 2012). Better local level access to ICT tools serves to enlarges personal networking options and availability (Castells, 2010), while low levels of access to ICT and other mobility tools (such as different transportation modes) makes it difficult to keep in contact with long-distance

network members, leading to networking more frequently at the local level (Kowald et al, 2013; Larsen et al, 2006; Matous et al, 2013).

In relation to network composition, the creation of homogeneous networks can also be explained by individuals being already sorted by various characteristics (such as age, gender, ethnicity or race, and socio-economic status) in shared environments such as schools, workplaces, or neighbourhoods (Liben-Nowell et al, 2005). In these locations, through constant interactions and shared interest, relationships are gradually formed (Ryan, 2007). In terms of forming interethnic relationships, there is a higher probability of ties being formed with natives when individuals tend to live in the same neighbourhoods as the natives themselves (Eisnecker, 2019). Adaptation into the surrounding environment is therefore important and visible within the context of migration, where the longer individuals have been living in the same place of residence, neighbourhood, city, or country, the more that local level networks are formed and social activities are conducted at the local level (Carrasco et al, 2008). Interlinking with native populations following a transnational residential mobility event is found to increase as the time spent at the destination also increases (Ryan, 2007; Verdery et al, 2018). Denser and more complete networks which are formed with the natives tends to ease the process of assimilation into the host society (Verdier & Zenou, 2017).

The high concentration of different social groups in different environments (such as in terms of race, ethnicity, or socio-economic status), which is something that is also known as spatial segregation (Mägi et al, 2016; van Ham et al, 2018;), also complicates the process of forming relationships between these different social groups. This type of spatial concentration is often explained by some locations being more easily accessible to some socio-economic groups, while for others such access may be limited or even impossible (Krysan & Crowder, 2017). The clear link between ethnic and socio-economic segregation is also found in societies due to the existence of usually limited opportunities for ethnic minorities, something which is often a result of a lack of language skills and the existence of a lower socio-economic status (Järv et al, 2021; Krysan & Crowder, 2017). These oppressed groups, which are often separated from the more socially-preferred groups, tend to experience difficulties when it comes to being able to diversify their social relationships and, as a result, access an increased number of resources and information (DiMaggio & Garip, 2012; Marques, 2012; Portes, 1998). Higher social status (such as possessing a higher level of income and education) is found to be related to the presence of an increased number of interethnic (bridging) ties, while also being the result of better financial opportunities in terms of being able to reside in areas in which the concentration of natives is higher (Barwick, 2017; Martinovic, 2013). These more ethnically heterogeneous networks may also deliver more information and a greater variety of opportunities, helping one to settle into more highly mixed residential areas (Peters et al, 2019), and to break through the vicious circles of segregation which are otherwise produced and reproduced throughout the space (Krysan & Crowder, 2017; van Ham et al, 2018).

Spatial segregation has been found to be at its most visible at the level of residential neighbourhoods (Boterman & Musterd, 2016; Musterd, 2005; Musterd

et al, 2017), but it has also been seen to be present in workplaces (Ellis et al, 2004; Hall et al, 2019), as well as leisure activity locations (Kamenik et al, 2015; Kukk et al, 2019), and activity spaces as a whole (Silm & Ahas, 2014; van Kempen & Wissinik, 2014; Wong & Shaw, 2011). As segregation in leisure activity locations seems to be somewhat less visible (Silm & Ahas, 2014; Silm et al, 2018; Toomet et al, 2015), public space and venues are often expected to facilitate interactions and integrations between different members of society. However, such interactions are still found to be somewhat limited, since it is not only people from minority groups, but also those from the majority ethnic group and people who have a higher socioeconomic status who often tend to self-segregate themselves from minorities and people who have a lower socio-economic status (Priest et al, 2014; Shinew et al, 2004; Wang & Li, 2016; Yip et al, 2016). The study of network-based homophily is something which can be considered useful when it comes to being able to understand prejudice and other attitudinal measures within the context of race and ethnicity, all of which tend to create strong divides in societies (McPherson et al, 2001). Common interests or concerns, an adequate level of trust, and language proficiency are some prerequisites which have been found to further increase contact between different social and ethnic groups (Grossetti, 2005; Heizmann & Böhnke, 2016).

2.6 Mobile phone data-based methods for studying relationships between personal social networks and spatial mobility

Due to some extremely rapid changes in society and technology over the past few decades (Castells, 2010; Sheller & Urry, 2006), the connection between personal social networks and spatial mobility has received increasing levels of attention. However, because this is a highly interdisciplinary field, there exist a number of field-specific approaches (such as transportation studies, sociology, physics, and others). As the study regarding the connection between personal social networks and spatial mobility needs suitable statistical data, studies which are conducted in this area can broadly be divided in two. Firstly, studies exist which have used more traditional methods, such as surveys and interviews, which have been combined with name generators and interactions diaries (e.g., see Carrasco & Miller, 2006; Guidon et al, 2018; van den Berg et al, 2012). Another and more contemporary strand of such studies explores these connections by taking advantage of location-aware forms of technology and datasets which have been based on the use of such technology, something which is also known as ‘Big Data’ (Harrison et al, 2020). Here, the most frequent use tends to be in the form of mobile phone-based data (Calabrese et al, 2011; Shi et al, 2016; Wang et al, 2015) and social media data (Grabowicz et al, 2014; Heidemann et al, 2012; Kane et al, 2014).

This current thesis is investigating relationships between personal social networks and spatial mobility, based on the use of mobile phone usage-based data.

Such data has been found to be suitable for this kind of research as it consists of data both in terms of interactions between mobile phone users as well as in terms of the physical locations of those individual phones (Blondel et al, 2015). Two types of mobile phone data are most widely available for such purposes: 1) 'Call Detail Records' (CDRs) and call-graphs which are provided by service providers (MNOs) (e.g., see Calabrese et al, 2011; Onnela et al, 2011); and 2) data which has been collected via smartphone applications (Stopczynski et al, 2014), and with both of these forms of data having been used in the analysis for this thesis.

When compared to more traditional forms of data collection, data which has been collected through the use of mobile phones can automatically be stored as a result of our daily activities. All phone use leaves traces, either in the databases of service providers or in those from which data collection is organised (e.g., see Masso et al, 2020; Stopczynksi et al, 2014). 'Call Detail Records' and mobile communications-based call-graphs consist of information which is related to one's call activities (Silm et al, 2020). Modern smartphone applications make it possible to collect an even richer set of information which is not only based on detecting phone use events, but which is also gathered through various sensors (such as GPS, Bluetooth, etc) (e.g., see Stopczynski et al, 2014). Through direct contact with the study participants, smartphone-based data collection also makes it possible to combine this with more traditional methods within the study group (such as surveys or interviews). This can be collected either directly, face-to-face, or through the same smartphone-based applications (e.g., see Linnap & Rice, 2014). Smartphone data, however, tends so far to be less frequently used when it comes to investigating relationships between personal social networks and spatial mobility (e.g., Dissing et al, 2018).

The use of mobile data requires suitable and meaningful information to be extracted from these collected datasets. Call-graphs are created by basing them on call activities which have been conducted between the mobile phone users. They mainly consist of information both for users who initiated the call activity in question and for users who received the call activity, while also including the time at which the call activity was made. To be able to study personal networks by using this data, the reciprocity measure is often used to detect calling partners which have a higher level of importance. This means that, over the time periods being considered, there must be activities which have been initiated by both parties who serve to form the relationship in question (e.g., see Onnela et al, 2007). This is done with the aim of excluding call activities which are related to purposes other than socialising (such as sales calls). To be able to measure the strength of the tie, the amount of call activities, along with their duration, between the specific users also must be considered (e.g., see Carron et al, 2016; Palchykov et al, 2013). The time frame which is involved here is important since it allows networks to be captured across a specific period of time, with these possible varying in size and stability across study periods which have different levels of duration (such as 30 or 180 days) (Krings et al, 2012).

Spatial information for all mobile phone users in terms of their CDR data has been made available at the level of the mobile antenna service area. To be able to

determine locations with higher levels of importance, such as home and work-time anchors, consideration has been paid to the volume of call activities and their timings in various locations (e.g., see Ahas et al, 2010; Phithakkitnukoon et al, 2012). In rather a small number of studies the information is made available not only for the antenna which provided the connection for a user who initiated a call activity, but also for the antenna which provided the connection to the user who received the call activity, allowing to study distances during call activities (e.g., Moyano et al, 2012). Information which is based solely upon the connecting antennas has been widely used in studies which have applied community detection methods (e.g., see Expert et al, 2011; Ratti et al, 2010). The smartphone information makes it possible to collect spatial information with even higher levels of precision based either on GPS or other sensors, such as detecting WiFi access points (Stopczynski et al, 2014).

Studies which connect calling-callipartner networks and spatial information have been used to investigate the geographical distribution of networks and their constraints (Lambiotte et al, 2008; Onnela et al, 2011). The effect of distance in terms of probabilities when it comes to the formation of a relationship between phone users has been the focus for a good many studies (for instance, see Deville et al, 2016; Shi et al, 2016). As mobile phone data allow us to study visited locations in the geographical space, various aggregated and geometric outputs can be used such as different areas visited (e.g., see Silm et al, 2018), or geometric shapes such as activity space ellipses (e.g., see Järv et al, 2014). Therefore some studies have also focussed on the relationships between mobile phone users through the study of activity space, where the overlap can be evaluated between activity locations which have been visited and mobility similarity for connected users (e.g., see Fan et al, 2017; Wang et al, 2015). The distance of visited locations from the places of residence of network members is something which is also measured (e.g., see Cho et al, 2011; Phithakkitnukoon et al, 2012).

The use of mobile phone-based data enables us not only to study spatial distribution, but also to combine it with measures which are related to time. For example, the inclusion of a time measure allows us to study different mobile phone users who are sharing the same spatial location and at the same time, something which is also known as ‘co-presence’ (for instance, see Toomet et al, 2015). In technical terms, and in terms of CDR data, this means sharing the same antenna during a limited timeframe (e.g., see Calabrese et al, 2011). When home anchor points are detected for different time periods, this makes it possible to study migration based on changes in place of residence, with those changes having effectively been connected to changes in activity spaces (Kamenjuk et al, 2017), and personal communications patterns (Fudolig et al, 2021). When mobile phone communications data becomes combined with survey results, the changes in networks and communications patterns are also studied in relation to other relocations, such as the transition from school to university or work (Saramäki et al, 2014).

As a highly sensitive information, all the mobile phone-based datasets which are used can also be linked to a substantial number of privacy concerns, as the

data consists not only of information about the study subjects themselves, but also their network members (Blondel et al, 2015). Therefore the data is provided only for use by MNOs, under strict terms and conditions, and in a form in which phone numbers are anonymised and which does not allow the data to be connected to a specific individual to ensure the anonymity of the mobile phone users (Saluveer et al, 2020). Data collection via a smartphone application also requires agreement between the side which is collecting the data and the smartphone users, with informed consent having to be signed by study participants. The consent outlines the purposes to which the data is to be used, the form in which it will be used, and by whom it will be used. Similarly, the data is only used and processed in a form which does not make possible any identification of study participants. The use of mobile phone data must be consistent with the various requirements and directives which have been set out in terms of the collection, storage, and processing of personal data, including those which may arise from the 'General Data Protection Regulation' (GDPR) (European Parliament & Council of the European Union, 2016).

3. METHODOLOGICAL FRAMEWORK

3.1 Data

The thesis is based on three articles using data which had been collected via mobile phones to investigate the relationship between personal social networks and spatial mobility. The study area in all three studies is limited to the borders of Estonia, within which are located observable personal social networks and spatial behaviour. The study periods fall within 2013–2017 and range from one month to one year, according to the data available and the purpose of the study (Table 1).

To be able to study the relationships between mobile phone users and their spatial behaviour, passive mobile positioning data which is stored automatically in the memory or log files which are held by MNOs (Silm et al, 2020) were used first (**Articles I, II**). The datasets consist of two types of data: a) call-graph data; and b) 'Call Detail Records' (CDRs) (Figure 2). Call-graph data consist of the pseudonymous identification codes both for those users who initiated call activities (user ID), and those users who received said call activities (recipient ID), along with the timings at which such call activities (calls, text messages, and multimedia messages) were conducted between users. CDR data is collected when the user initiates the outgoing call activity. It consists of the time at which the call activity is carried out and information regarding the connected antenna, including its coordinates (x, y). The same pseudonymous IDs in both datasets makes it possible to trace the same users over time and to link CDR data with call-graph data (Figure 3). At the same time, phone users cannot be associated with a specific individual or phone number and, therefore, this process ensures the anonymity of phone users (Saluveer et al, 2020). As the analyses are based on datasets which have been provided by only one MNO, the CDR data is available for all IDs who are clients within the same MNO.

Call-graph data

user id	recipient user id	call time
304113	4456112	12.03.2012 8:13
8099223	5543221	12.03.2012 9:56
5543221	8099223	13.03.2012 10:23

CDR data

user id	call time	antenna id	x	y
304113	12.03.2012 8:13	567	27.4475	58.1144417
8099223	12.03.2012 9:56	118	24.762075	59.4325861
5543221	13.03.2012 10:23	118	24.762075	59.4325861

Figure 3. Linking the following: a) call-graph data; and b) call detail record (CDR) data, based on user IDs.

Based on spatial distribution from antennas, the location accuracy of passive mobile positioning data is better in densely populated areas or in areas which have denser road networks, where the location accuracy levels range between 100–500m. In more sparsely populated areas, this can reach as much as 500–5000m (Ahas et al, 2008). Both studies include data from MNOs whose networks cover nearly 99 percent of the territory of Estonia. Therefore the study area covers the entirety of Estonia and a total ground of 45,000km^2. Nearly 94 percent of the population in Estonia could be counted as a mobile phone user in 2013 (Eurobarometer, 2013).

In addition to call-graph and CDR data, the gender, year of birth, and preferred communications language of every phone user is also provided for scientific purposes. The language (whether Estonian, Russian, or English) is chosen by every mobile phone user when they sign a contract with the MNO. To be able to identify the place of residence and workplace locations for each mobile phone user the anchor point model is used, which is based on the timing and location of call activities (Ahas et al, 2010). In articles which have been included in this thesis, only one main residence and one work-time anchor was assigned to each person. When using the same MNO, the places of residence of calling partners were similarly detected.

To be included in the analysis based on the use of passive mobile positioning data, phone users had to meet various criteria due to the focus of the study or the under-representation of some groups. For example, as the special focus of the analysis was on calling-partner networks, at least 50 percent of all activities were required to take place inside the same MNO to guarantee the inclusion of the majority of calling partners when it came to calculating network characteristics (**Article I**). Reciprocal call activities had to be detected with at least one of the calling partners to be able to define members of networks. Mobile phone users with languages which were either Estonian or Russian were included, while English speakers were excluded due to their under-representation. The analysis was conducted with a special focus on the ethno-linguistic composition of networks, which also required the language identifier to be known for at least one of the calling partners (**Article II**). All of those mobile phone users who were included in the analysis were aged 19 or older due to the under-representation of younger groups in the data. Home and work-time anchors had to be known for mobile phone users as these were essential characteristics in assessments (**Articles I, II**). The first study was conducted using passive mobile positioning data, which included a total of 70,536 mobile phone users who were residing across Estonia, with call-graph data which was accessible for the period between 18–28 February 2013 (covering a span of 11 days), and CDR data for the whole of February 2013 (an entire month) (**Article I**). The second study included 13,021 mobile phone users who were residing in Tallinn, Estonia's capital. The study period covers the period between January and December 2016 (one entire calendar year), both for call-graph data and for CDR data (**Article II**).

Data which had been collected via the smartphone application, MobilityLog, forms the second type of mobile phone data to be used in this thesis (**Article III**).

The Android-based application which was used for data collection is designed for long-term mobility tracing and social-network-related experiments, and is jointly developed by Mattias Linnap and the Mobility Lab, University of Tartu (Linnap & Rice, 2014; Poom, 2019). The metadata from call activities and GPS data which was collected by the application is used to investigate the relationships between personal social networks and spatial mobility. As the focus of the study was on domestic behaviour, call activities and GPS data were only included for the days upon which there was spatial data available from within Estonia's borders.

Call activity data which was collected by the application consisted of the anonymised phone numbers of calling partners (with three digits having been replaced by the system), along with the type of call activity (whether it was a phone call or text message), the direction (whether incoming or outgoing), and the time at which the call activity took place (including the start and end times). This information was further used to gather additional details about network of calling partners during the post-survey which was carried out following the conclusion of the data collection period. The information was asked of about the ten most important partners, based on reciprocity (involving at least one incoming and outgoing call activity with a partner), and the highest activity rank, thereby forming an individual personal social network within the context of the study (**Article III**). The information which was gathered consisted of a partner's place of residence (whether they were sharing the same place, along with the municipality in which their residence was located), the partner's role, relative closeness, the frequency of face-to-face meetings, and the most common meeting location. Based on this information, various social network variables could be derived. Quantitative face-to-face surveys (pre-data collection and post-data collection) took place to additionally gather information about an individual's socio-demographics, along with the use of ICTs and social media, which were used as descriptive characteristics.

GPS data collected by the application makes possible a study of spatial mobility levels with higher levels of accuracy in terms of time and space when compared to what could be gathered from CDR data. To identify activity locations from movement points and to reduce the overall data volume for the analysis, use was made of clustered GPS points – known as 'stops' – as the basis of the analysis. The methodology being employed for calculating stops uses individual GPS points based on their time and distance, with this process having been developed by a company Positium during the project, 'Campus Areas as Labs for Participatory Urban Design' (Poom, 2019). The methodology is described in more detail in **Article III**. To be included, study subjects were required to have spatial data collected for at least half of the study period, between 1 August 2016 and 31 July 2017. Additionally, they had to live and study or work in Tartu in Estonia during the one-year study period. Accordingly, the study is based on data which has been collected from a total of 80 individuals, with participants either being students (n=39, totalling 49 percent) or staff members (n=41, totalling 51 percent) at the University of Tartu (**Article III**). Therefore they are expected to represent one of the crucial population groups in this university city in terms of mobility and social

networks. As a more 'highly skilled' group, this also makes it possible to study and understand the broader spatial context: highly skilled individuals tend to have larger and more spatially-dispersed networks (Kowald et al, 2013), while also proving to be more mobile (Carrasco & Miller, 2006), and using more ICTs (Wang & Law, 2007). Participation in data collection was voluntary, with the study subjects being recruited either through direct contact (for employees) or through university contact lists (for students). Participation was made possible for study participants by using smartphones which were provided free of charge, or with their own phone.

For all of the studies, data as provided was entirely used for scientific purposes. There are various steps taken in terms of data collection, storage, and processing to ensure the privacy of study participants. Anonymised ID-based analysis only took place in a restricted environment on the servers of the University of Tartu, with no links to any personal identifiers (name, phone number, or email address, for example). All of the analyses were carried out in a way which did not permit study participants to be identified, and the data could be exported from the systems only in an aggregated form. Contracts were signed by all of those researchers who were responsible for conducting the data analysis, which outlined the rights of everyone involved, along with the form in which any data would be used and the purposes to which it would be put. Participants in the MobilityLog study installed the application only after they had signed an informed letter of consent to participate in the study (**Article III**).

3.2 Analysis parameters

One's personal social network and spatial mobility are the two central phenomena to have been included into this thesis. **Personal social networks** are studied from the standpoint of an individual (being ego-centric). They consist of calling partners with whom study subjects have been conducting call activities over the included study periods. The reciprocity of call activities is used as a criterion to determine the members of networks in all three studies (Table 1). This criterion for inclusion is widely used in other studies which access mobile phone-based datasets with the purpose of excluding non-essential one-way numbers which often represent, for example, different services (e.g., see Carron et al, 2016; Onnela et al, 2007). When studies which are using passive mobile positioning call-graph data include all of the reciprocal partners (**Articles I, II**), studies which use data which has been collected through a smartphone application limit networks to a maximum of ten (10) of the most important reciprocal calling partners, based on the share of call activities (**Article III**). The limit (10 partners) was set due to time constraints and the requirement for an optimum survey length since network-related questions formed only one part of a more comprehensive data collection. However, as the number of call activities is often used as an indicator of the strength of the relationship (Dunbar, 2016; Palchykov et al, 2013), the data is still useful. The method is probably more effective in terms of capturing those affective and close networks

which are needed to understand individual outcomes, such as social activities and travel (e.g., see Tillema et al, 2010).

The main characteristics of personal social networks which are used in analysis are related to the spatial distribution of these networks (Table 1). These involve the number of districts or municipalities in which calling partners reside (**Articles I, II, III**), along with the diversity of partner residences across municipalities (**Article III**), and the average distance to calling partner residences (**Articles I, III**). Additionally, the size of the networks (**Article I**) and their ethno-linguistic composition (whether co-ethnic or interethnic) (**Article II**) are used as the main variables in the analysis. Individuals are considered to have a co-ethnic network when all their calling partners use the same preferred language as the mobile user concerned. Interethnic networks, on the other hand, include at least one calling partner who use a different language. To describe the differences in emerging connections with mobility, various other network related variables also have been used. These include the composition of networks (the share of partners which involve each role and closeness level), along with shares of frequencies of face-to-face meeting, and the most common meeting locations (**Article III**). Three network variables were also extracted from call activity data, with these being the average share of days in which call activities with a partner took place, the average number of call activities per day with a partner, and the average duration of calls per day with a partner (in seconds). These were calculated for partners who resided outside of the study subject's place of residence (**Article III**).

Spatial mobility in this thesis is measured through the approach to activity space (**Articles I, II, III**) as well as the distances travelled (**Article III**). The extent of activity space is measured either as the number of different districts or municipalities which have been visited during the study period (**Articles I, II**), or the area of the activity space ellipse (**Article I**). The activity space ellipse as a standard deviational ellipse represents the smallest possible area in which a person has conducted their call activities during the study period, with a probability of 95 percent, and in which the number of call activities in each location is used as a weighted measured when calculating the ellipse (for instance, see Järv et al, 2014). Measures such as the average number of municipalities and distance travelled per day, and also the diversity of municipalities visited, are also used, with the latter referring to how equally individuals have spent their days across different municipalities which serve to form the activity space (**Article III**). The central measures for activity space also include its ethnic composition in terms of the percentage of Russian residents in residential and workplace areas, and in all the visited districts. These measures are derived according to 2011 census data (involving the total number of Estonians and Russians, according to mother tongue), and were used to reflect exposure to ethno-linguistic groups within these districts (**Article II**) (Table 1).

Finally, those background variables which are used to describe differences in relationships involve personal characteristics such as the gender (**Articles I, II, III**), age (**Articles I, II, III**), communication language (**Articles I, II**), relationship status, the presence of children under the age of 18, and the net income per

household member (**Article III**). Additional ICT usage variables were also used. These included the share of users and usage frequencies for the various available ICT tools and social media channels to describe the emerging relationships between the spatial distribution of personal networks and spatial mobility (**Article III**). Background variables also include the settlement-system hierarchy level in which individual lives and distances between home and work-time anchors (**Article I**).

3.3 Analysis methods

Relationships between network of calling partners and spatial mobility have been analysed by using various available methods (Table 1). To be able to see the general relationships between calling-partner networks and spatial mobility parameters, Spearman's (2-tailed) rho correlation analysis has been used. This made it possible to estimate relationships between personal social networks (involving their size and spatial distribution) and spatial mobility variables (**Articles I, III**). In one study, the correlations have also been calculated separately for groups, based on their socio-economic characteristics and those of daily locations so that differences can be seen in these relationships (**Article I**). Correlation analyses are also used to examine associations between the number of individuals who have interethnic networks and Russian residents in residential and workplace districts, with the same test being carried out separately for Estonian- and Russian-speakers (**Article II**).

Regression models are used to include the effects which are induced by different individual, network-related, and ICT usage variables (**Articles I, II**). The general linear model (GLM) is used to study the effect of characteristics of the personal networks on the extent of activity space, while also incorporating socio-demographics and characteristics of daily locations into these models (**Article I**). A set of binary logistic regression models was applied to discover how different variables affect the odds of having an interethnic network, with socio-demographic variables, and activity space characteristics included as independent variables (**Article II**). Negative binomial regression and OLS regression were used to further discover relationships between the ethno-linguistic composition of networks and spatial mobility, for which dependent variables included indicators of activity space, while the main explanatory variable being used was the ethno-linguistic composition of social networks. All these models were created jointly for everyone who was included in the study, and then again separately for Estonian-speakers and Russian-speakers (**Article II**). All these models serve to make it possible to study relationships between personal social networks and spatial mobility, although they do not refer to the causality, but are instead used to explore relationships between those variables which are being used for the analysis.

Table 1. An overview of data used, main analysis variables of personal networks and spatial mobility, and methods used in **Articles I, II, and III.**

	Article I	**Article II**	**Article III**
Study subjects	• 70,536 mobile phone users residing in Estonia	• 13,021 mobile phone users residing in Tallinn, Estonia	• 80 smartphone users residing in Tartu, Estonia
Type of data	• Call-graphs • Passive mobile positioning data (CDR) • Social characteristics	• Call-graphs • Passive mobile positioning data (CDR) • Social characteristics	• Call-graphs • Active mobile positioning data (GPS) • Related quantitative surveys *(socio-demographics; the use of ICTs and social media; information about calling partners)*
Study period	• 18–28 February 2013 (call-graph; 11 days) • February 2013 (CDR; 1 month)	• 1 January–31 December 2016 (1 year)	• 1 August 2016–31 July 2017 (1 year)
Type of network	• Ego-centric, all reciprocal partners	• Ego-centric, all reciprocal partners	• Ego-centric, 10 reciprocal partners with most activities
Main variables of personal social network	• Number of calling partners • Number of districts in which partners reside • Average distance to partners' residences	• Ethno-linguistic composition of social networks (co-ethnic, interethnic)	• Number of municipalities in which partners reside • Diversity of partners' residences across municipalities • Average distance to partners' residences
Main variables of spatial mobility	• Number of visited districts • Area of activity space ellipse	• Number of visited districts • % of Russian residents in residential district • % of Russian residents in workplace district • % of Russian residents in districts visited	• Average number of daily visited municipalities • Diversity of days spent across visited municipalities • Average distance travelled per day
Analysis methods	• Spearman correlation analysis • General linear model (GLM)	• Spearman correlation analysis • Binary logistic regression • Negative binomial regression • OLS regression	• Spearman correlation analysis • K-means cluster analysis • Independent Samples Kruskal Wallis one-way ANOVA and Cramer's V • Binary logistic regression

By looking at other methods, a typological approach and k-means cluster analysis is used to investigate the diversity of the relationships (**Article III**). This method provides an understanding of the specific structural nature of the relationship because it divides the study participants into different types based on the spatial distribution of their calling partners and their spatial mobility levels. This became the selected method as it has proven its suitability for this form of typological analysis in research which has already been conducted by others (for instance, see Cachia & Maya-Jariego, 2018). The statistical criteria in the ANOVA test were used to estimate any statistically significant differences in terms of spatial distribution of personal social network and also spatial mobility across clusters. Additional agglomerative techniques (such as hierarchical cluster analysis) were used to test the persistence of the final cluster structure.

To further explain the formation of the network and spatial mobility types which have been created, these resulting clusters were further analysed in relation to other background characteristics (**Article III**). The 'Kruskal Wallis Independent Samples' one-way ANOVA test was first conducted for continuous variables while Cramer's V was used for categorical variables, to discover the existence of any statistically-significant differences in background characteristics between the types. To highlight a non-spurious relationship between these variables, all statistically significant socio-demographics, network-related, and ICT and social media usage variables, were subsequently included as independent features in the binary logistic regression models. Separate models were created to be able to evaluate the three types in comparison.

3.4 Study area

The study area in the current thesis is the Baltic state of Estonia, which has a total population of 1.3 million inhabitants (Statistics Estonia, 2011). In the first study (**Article I**), the places of residence of study subjects are located across the entire country (Area 1 in Figure 4). Based on the population density and labour migration, the municipalities of Estonia are divided into eight settlement-system hierarchy levels on the basis of population and housing census 2011 (Statistics Estonia, 2011). Accordingly, the hierarchy levels are divided into cities (capital city, regional centres, county towns, small towns), commuting areas of the cities, and rural areas (Figure 4). Commuting areas are the suburban areas, in which at least 15 percent of residents of these municipalities worked either in the capital city, regional centres or county towns.

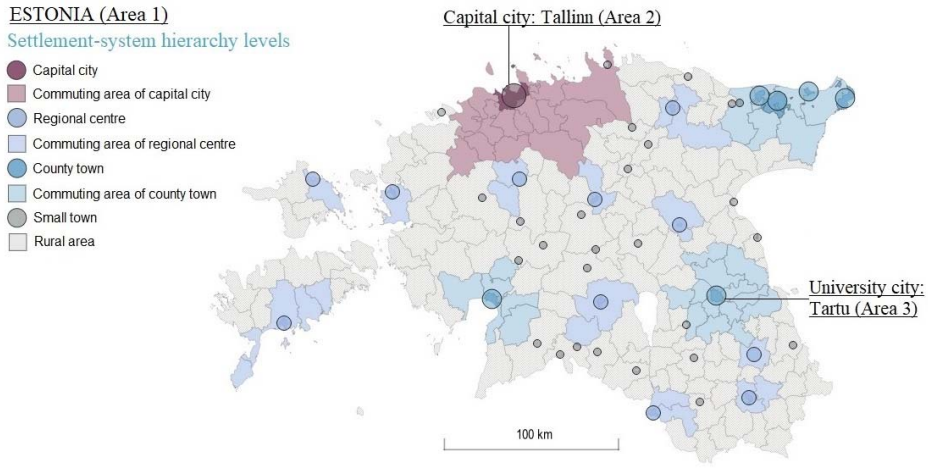

Figure 4. The areas where study participants live and the distribution of settlement-system hierarchy levels.

In the second study (**Article II**), only mobile phone users were included if they were residing in Tallinn, where 30 percent of the total population lives (Area 2 in Figure 4). The third study (**Article III**) used data which had been collected via a smartphone application and included a smaller group of individuals who were residing in Tartu (Area 3 in Figure 4). The total population of Tartu amounts to almost 100,000 inhabitants, forming 7.5 percent of the country's total population (Statistics Estonia, 2011).

Estonia's population is mainly divided between two ethno-linguistic groups: the majority is Estonians (forming 69% of the total) (Statistics Estonia, 2011), while 28 percent consists of various nationalities which together are often termed the Russian speaking minority (such as Russians, Ukrainians, Belarussians, etc) (Vihalemm, 1999). The proportions of the two groups are more similar in the capital city of Tallinn, where 55 percent of the inhabitants are Estonian-speakers and 43 percent are Russian-speakers. In Tartu, Russian speakers account for only 14 percent of the total number of residents (Figure 5) (Statistics Estonia, 2011). The high share of Russian-speaking residents in Estonia has largely been the result of the residential and labour market policies of the former Soviet Union, which led immigrants to settle in high-rise housing estates in the larger cities and around the larger industrial areas (Kährik & Tammaru, 2010). Tallinn itself has more Russian speakers in its eastern areas while Estonian speakers are more generally concentrated towards the southern part of the city (Figure 5). At a broader level, Russian residents form the majority population in many areas around the northern and eastern parts of Estonia (Figure 5).

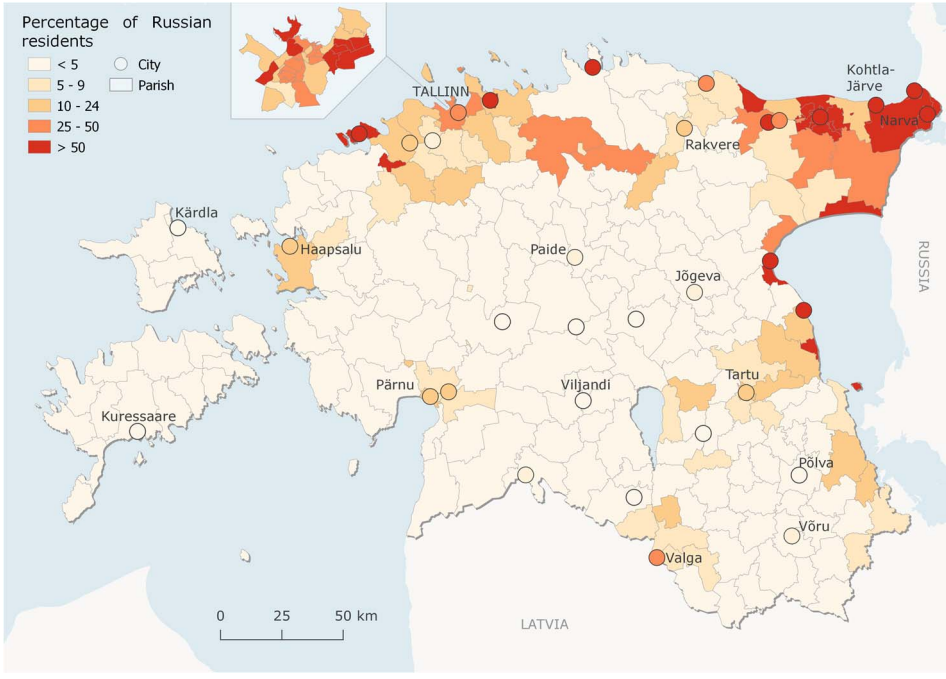

Figure 5. The distribution of the Russian-speaking minority population in Tallinn and Estonia, according to the 2011 census (Statistic Estonia, 2011). Source: **Article II** (Silm et al, 2021).

Segregation in Estonia does not exist alone in places of residence, but also in schools and workplaces (Tammaru & Kulu, 2003). In Estonia, the limited levels of interaction and networking between the country's majority population and its minority population has also resulted from the linguistically-separated school system, whether in kindergarten or during basic education, which additionally leads to limited proficiency in the use of the Estonian language (Masso & Soll, 2014). Although the majority and minority populations are also separated by the fact that they tend to work in different sectors of the economy (Tammaru & Kulu, 2003), contacts between ethno-linguistic groups are more common in relation to employment-related interactions, and those which are related to the service sector (Korts, 2009). Personal networks in Estonia are continuously segregated along ethnic lines (Vihalemm, 2007), where contact between the majority and minority populations is noticeably more rare (Korts, 2009). Ethnic segregation has also been found to be relatively stable across generations (Silm et al, 2018). Several studies have already been conducted which also show significant differences in the activity spaces of these two ethno-linguistic groups. The Russian-speaking minority has been found to have significantly smaller activity spaces when this is compared to the spaces being used by Estonian-speakers (for instance, see Järv et al, 2015; Silm et al, 2018).

4. RESULTS

4.1 Relationships between the spatial distribution of networks and spatial mobility

The spatial distribution of calling-partner networks and spatial mobility within the context of Estonia is rather limited, as people tend to live in the same districts and municipalities as their calling partners. More than half (totalling 57 percent) of ten most important calling partners which were studied tend to live in the same municipality as the study subject, and the average distance to their places of residence is 57 kilometres (**Article III**). When all the reciprocal calling partners are studied, the average distance to the residences of calling partners is 26.2 kilometres (**Article I**). Daily mobility is similarly concentrated near place of residence with, on average, study subjects having been in their home municipality for 80 percent of days, and with visits taking place to other municipalities on 33 percent of days (people can stay in more than one municipality on the same day) (**Article III**). However, despite the high spatial concentration shown here, individuals who have more dispersed networks and levels of spatial mobility can also be found (**Articles I, II, III**).

A significant relationship exists between the network of calling partners and spatial mobility. This is something which has been found in all three of the articles which have been included in this thesis. The spatial distribution in the calling-partner network is first found to be connected to the extent of the activity space for individuals. Those individuals who have networks with members who live in a higher number of districts and further apart are having spatially broader activity spaces, both according to the number of visited unique districts and the ellipse which covers area of activity space (**Article I**). The number of visited unique districts which serve to form an individual activity space has the strongest level of connection with the number of districts which contain the residences of calling partners ($r=0.483$; $p<0.01$). The area which makes up the activity space ellipse, in turn, has the strongest relation to the average distance to partner residences ($r=0.366$; $p<0.01$) (Table 2). The characteristics of social networks remain just about the most important factor in relation to an individual's activity space in the general linear model, when the effects of personal characteristics, and parameters such as the settlement-system hierarchy level of home districts and the distance between home and work, can be monitored (Table 3 in **Article I**). In these models, the number of districts which contain the residences of calling partners tends to cover 13.0 percent of the variance in the number of visited districts. The average distance to the residences of calling partners accounts for much of the variation within the area of the activity space ellipse (totalling 4.5 percent of the variance).

The extent of daily mobility is similarly related to the spatial distribution of networks, which is something which can be confirmed by the analysis conducted amongst a smaller group of 'highly skilled' individuals who were living and working or studying in Tartu (**Article III**). People who had spatially more-

dispersed personal social networks tended to visit a higher number of municipalities per day, while also spending their days more equally across the various municipalities they visited, and travelling a higher total of kilometres per day. In relation to daily mobility, the strongest connections can be found between the average number of municipalities which were visited per day and the spatial distribution of networks. The study subjects tended to visit a higher number of municipalities per day when the average distance to the residences of network members is longer ($r=0.892$; $p<0.01$), and when those residences are more equally distributed between two or more municipalities ($r=0.574$; $p<0.01$) (Table 2). A somewhat weaker connection exists in terms of the number of municipalities in which network members reside ($r=0.273$; $p<0.05$). The study subjects also spent their days more equally across those municipalities which they visited when their network members were divided more equally across municipalities ($r=0.223$; $p<0.05$). They travelled a higher number of kilometres per day, on average, when the average distance to partner residences was longer ($r=0.278$; $p<0.05$), and the diversity of partner residences across municipalities was greater ($r=246$; $p<0.05$) (Table 2).

Table 2. Correlations between the characteristics of the ego-centric calling-partner networks and spatial mobility (Spearman's rho correlation analysis). Source: Table 2 in **Article I**; Table 4 in **Article III** *(modified table).*

	Article I *(N=13,021)*		**Article III** *(N=80)*		
	Number of visited unique districts	Area of the activity space ellipse (km^2)	Average number of municipalities visited per day	Diversity of days across visited municipalities	Average distance travelled per day (km)
Number of districts/municipalities[1] in which calling partners reside	0.483***	0.285***	0.273**	0.145	0.086
Average distance to calling partners residences[2]	0.320***	0.366***	0.892***	0.113	0.278**
Diversity of partners' residences across municipalities			0.574***	0.223**	0.246**

Notes: [1]Districts in **Article I** and municipalities in **Article III**; [2]Only the partners living outside the same place of residence were included in **Article III**; *p<0.1, **p<0.05, ***p<0.01

There is also a level of internal diversity in the relationship which was revealed through a typological approach (**Article III**), which indicates that more spatially dispersed networks do not necessarily lead to more spatial mobility. As a result of the cluster analysis, the study subjects have been divided into three different types based on their spatial distribution of networks when it comes to calling partners and spatial mobility: **Type A** *with spatially dispersed networks and high mobility*; **Type B** *with spatially dispersed networks and low mobility*; and **Type C** *with spatially concentrated networks and low mobility*. All the included network and mobility parameters continue to serve as relevant distinctive features of clusters in ANOVA ($p<0.01$) (Figure 6).

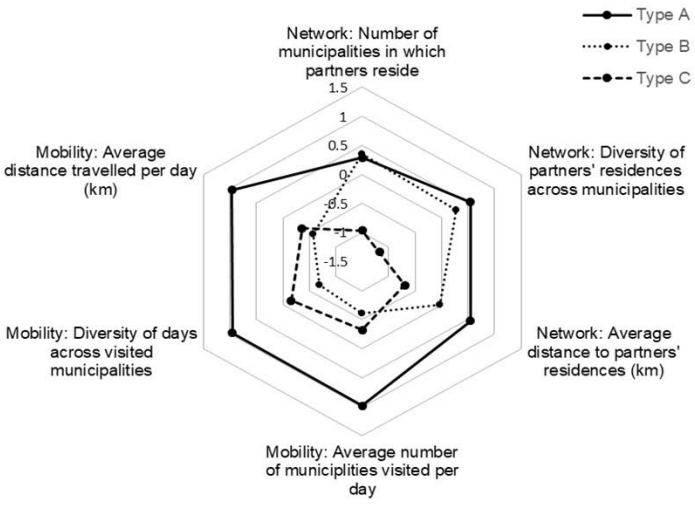

Figure 6. Cluster differences by spatial distribution of calling-partner networks and spatial mobility parameters. *Standardised values.* Source: Figure 2 in **Article III**.

Type A and Type C are consistent with the general trend: spatially dispersed networks relate to more spatial mobility (Type A), and spatially concentrated networks relate to less spatial mobility (Type C). However, Type B subjects have similar spatial distribution levels to Type A subjects, but they are less mobile in relation to their network, in which their mobility behaviour is like that to Type C subjects (Table 3 in **Article III**).

The first two types, A and B, therefore consist of subjects who have networks which are more spatially distributed, and in which their calling partners live farther apart, on average (Type A is at 78km; Type B is at 56km), and in more municipalities across which they are distributed more evenly (with a diversity index value of >0.60). In these groups, nearly half of calling partners live outside their home municipality (Type A: 57 percent; Type B: 44 percent). In comparison, study subjects belonging to Type C and who have concentrated networks have shorter average distances between themselves and the residences of their

calling partners (at 31km) and only 20 percent of their partners live outside the subjects' home municipality (with a diversity index value of 0.31).

In relation to spatial mobility, Type A subjects who are more mobile tend to visit a higher number of municipalities per day, and they spend their days more equally across the various municipalities they have been visiting (with a diversity index value of 0.64). Type A subjects can be seen to have visited other municipalities on a total of 48 percent of days, while they travel on average 35km per day. In comparison to this, people who belong to types B and C are less mobile, and their spatial behaviour is centred more around the home municipality (with a diversity index value of < 0.50). They visit other municipalities on less than 30 percent of days (Type B: 24%; Type C: 29%), and travel a lower total number of kilometres per day (Type B: 19km per day; Type C: 21km per day).

4.2 Personal characteristics which shape the relationships

There are various factors which serve to influence the relationships between personal social networks and spatial mobility, where the effect of gender and ethnicity are found as the most prominent in this thesis. According to gender, the spatial distribution of networks is more heavily related to the spatial extent of activity space for men than it is for women (**Articles I, III**). It is first presented by the correlation coefficients, in which the greatest differences are visible in the connection between the number of visited districts and the number of districts which contain places of residence of partners (male: r=0.518; female: r=0.389) (Table 4 in **Article I**). Gender is also the main socio-demographic variable which can be found when it comes to determining the belonging to the network and mobility types (Table 6 in **Article III**: Model 1 and Model 2). For men there are higher odds that they will belong to the type which has spatially dispersed networks and higher levels of mobility (Type A), than it is that they will be the type which has more dispersed networks and low levels of mobility (Type B) ($p<0.01$; Exp (B)=7.434), or the type which has concentrated networks and low levels of mobility (Type C) ($p<0.05$; Exp (B)=9.129), which tend to consist more of women. Type A subjects, who are mostly men, also more often tend to meet up with their partners in their partners' own residences, this being the most common shared meeting location with a higher share of partners (totalling 43 percent) when compared to the results for Type B (which has 31 percent; $p<0.01$; Exp (B)=0.964), or Type C (at 26 percent; $p<0.05$; Exp (B)=0.936). This further confirms the finding that men are not only spatially more mobile (Table 1 in **Article I**), but that their spatial mobility behaviour tends to be more often connected to visiting the places of residence of their network members.

Ethnicity is another significant factor which serves to shape relationships between personal social networks and spatial mobility within the Estonian context. Ethnicity affects both the spatial distribution of networks in Estonia and individual activity spaces, while Russian-speakers in Estonia have partners who tend to live in less different districts and across shorter distances when compared

to Estonian-speakers. Russian-speakers also visit fewer districts, and the area of their activity space is smaller than it is for Estonian-speakers (**Articles I, II**). When the spatial behaviour is studied of the two main ethno-linguistic population groups which are living in Tallinn, Estonia's capital city, it can be seen that Russian-speakers visit 8 percent fewer districts than do Estonian-speakers ($p<0.01$; Table 3: Model 4 in **Article II**). When the ethnic composition of the visited districts is considered, Russian-speakers tend to visit areas which have a higher proportion of Russian residents (on average 33 percent) when compared to the case with Estonian-speakers (25 percent) ($p<0.01$; Table 4: Model 8 in **Article II**). At the same time, the number of calling partner residential districts is important. The more districts in which calling partners live, the higher is the number of different districts which are visited. There were no significant differences between the two ethno-linguistic groups in this regard, and similar results were found in **Article I** (Table 4 in **Article I**) and **Article II** ($p<0.01$; Table 3: Models 4–7 in **Article II**).

4.3 ICT usage in shaping relationships

The size of the network of calling partners and ICT usage as a whole has been found to be important in terms of the relationship between the spatial distribution of networks or its relationship with spatial mobility. The size of the calling-partner networks has similarly been found to be related to the extent of one's activity space (**Article I**). The bigger in size is the network of calling partners, the higher is the number of visited unique districts ($p<0.01$; $r=0.420$) and the larger is the area of the activity space ellipse (kilometres squared) ($p<0.01$; $r=0.278$). This connection, however, differs when gender and ethnicity is taken into consideration. When comparing Russian-speakers to Estonian-speakers, and similarly considering females to males, it can be seen that Russian-speakers and females tend to have a weaker connection when it comes to the number of calling partners on the one hand and the extent of activity space on the other (Table 4 in **Article I**). This means that even when the number of calling partners is as high for females and Russian-speakers as it is for males and Estonian-speakers, females and Russian-speakers visit fewer districts.

A greater level of usage of ICTs is a matter which is related to having geographically more extensive networks, but not necessarily to higher spatial mobility (**Article II**). From this perspective, individuals have higher odds of belonging to Type A (spatially dispersed networks and high mobility), and Type B (dispersed networks and low mobility), than they do to Type C (spatially concentrated networks and low mobility) when they use more ICTs. It is found in terms of the duration of their calls each day with a network member, and also in terms of the frequency of use of their social media channels (such as Facebook and professional activity networks) (Models 1–3 in **Article III**).

4.4 Network composition in shaping relationships

The role and ethno-linguistic compositions of networks were found to be important in forming relationships between the spatial distribution of networks and spatial mobility. Firstly, the share of family members within the network has been found to be an important characteristic when it comes to being able to explain the spatial distribution of personal social networks. The networks of Type A (dispersed networks and high mobility) and Type B (dispersed networks with low mobility) subjects consist of a higher share of family members (totalling 45.2 and 40.6 percent, accordingly), when compared with the figures for Type C (concentrated networks and low mobility, totalling 26.4 percent) (Table 6 in **Article III**). The outcome which could be seen to be related to the role composition of personal networks is illustrated in Figure 7, which pulls together the main differences between the network and mobility types (**Article III**).

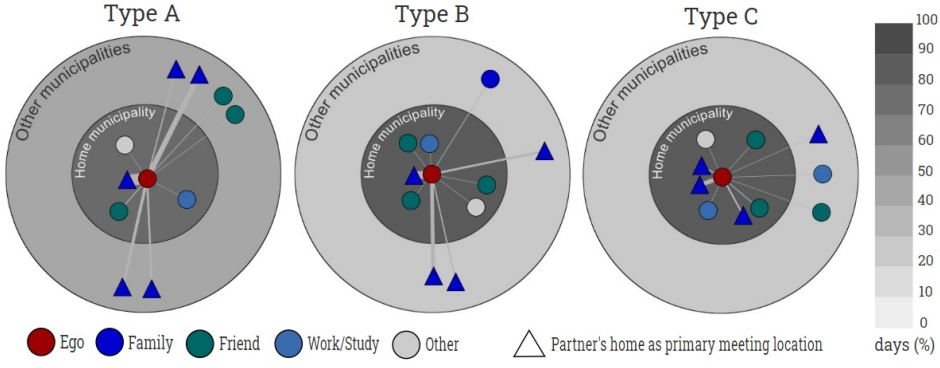

Figure 7. Spatial distribution of network of calling partners and days spent in different municipalities by types. The width of the link represents the duration of calls with a partner. Source: Figure 3 in **Article III**.

The ethno-linguistic composition of networks for both of the stated ethno-linguistic groups is related to the spatial extent of individual activity space. Russian-speakers tend to have smaller activity spaces, while having an interethnic network is something which is related to Russian-speakers having somewhat broader activity spaces. A total of 4 percent more districts are visited by Russian-speakers who have interethnic networks when comparing them to Russian-speakers who have co-ethnic networks ($p<0.01$; Model 7 in **Article II**). The outcome for Estonian-speakers is rather contrary, with Estonian-speakers who have interethnic networks tending to visit 12 percent fewer districts when they are compared to Estonian-speakers who have co-ethnic networks ($p<0.01$; Model 6 in **Article II**). Having interethnic networks relates to visiting areas in which the average proportion of residents from another ethno-linguistic group is higher ($p<0.01$; Models 10–11 in **Article II**).

The differences in spatial behaviour for both ethno-linguistic groups, either with co-ethnic networks or inter-ethnic networks, is also evident in geographical terms (**Article II**). Russian speakers who have co-ethnic networks are more likely to visit the northern and eastern regions of the country, and less so the western or southern parts which have lower concentrations of Russian-speaking residents. However, Russian speakers who have interethnic networks have more geographically-extensive activity spaces, while those districts which lay outside the northern and eastern regions of Estonia are also more likely to be visited (Figure 8).

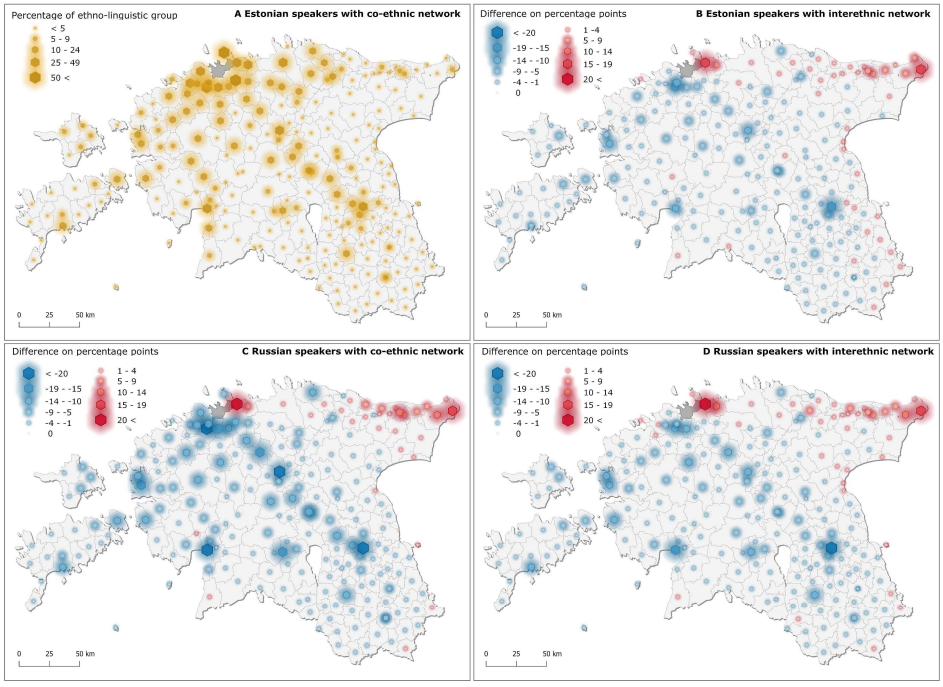

Figure 8. Comparison of visited districts by ethno-linguistic groups and their network composition: (A) Estonian speakers with co-ethnic networks (reference category), (B) Estonian speakers with interethnic networks, (C) Russian speakers with co-ethnic networks, and (D) Russian speakers with interethnic networks. Differences presented as percentage points (weighted data). Source: Figure 4 in **Article II** (Silm et al. 2021).

4.5 The characteristics of daily activity districts in shaping relationships

The formation of the link between networks and spatial mobility can also be explained by the surrounding daily context of an individual in terms of where their place of residence or workplace are located. In this thesis, the connection which was formed was related to the settlement-system hierarchy levels in which

individuals live, the distance between their home and work-time anchor points, and the ethno-linguistic composition of their home and workplace districts.

The location of their place of residence in different levels in the settlement-system hierarchy tends to shape the connection between the spatial distribution of their networks and their spatial mobility (**Article I**). Individuals who live within higher levels of the settlement system hierarchy, such as the capital city, its commuting area, or the regional centres, tend to have a stronger connection between the average distance to network members residences and the extent of activity space (involving the number of visited districts and the total area of the activity space ellipse). The connection is weaker for individuals who are living in county town commuting areas, small towns, and rural areas (Table 4 in **Article I**). Long distances between home and work similarly affect the relationship. There is a stronger connection between the average distance to network members places of residence and the number of unique districts to be visited when an individual works closer to home ($r>0.250$; $p<0.01$) when compared to individuals whose work-time location is over the longest distances (those of 50 or more kilometres from home) ($r=0.082$; $p<0.01$).

Ethno-linguistic composition in areas of place of residence and workplace is something which is related both to the extent of one's activity space, and also the ethno-linguistic composition of one's networks. Having a place of residence in area which have a higher share of Russian-speaking residents is found to be related to visiting areas in which the average percentage of Russian-speaking residents is higher. The result is found to be similar both for Estonian-speakers (Table 3: Model 10 in **Article II**), and Russian-speakers (Table 3: Model 11 in **Article II**). Similar findings are visible in terms of ethno-linguistic exposure in workplaces (Table 3: Models 8–11 in **Article II**). Visiting areas in which the share of Russian residents is higher is something that is also related to the ethno-linguistic composition of the districts in which calling partners live. From this aspect, the average share of Russian residents in visited districts is higher when the calling partners live in areas which also have a higher average percentage of Russian residents ($p<0.01$; Table 3: Models 8–11 in **Article II**).

The role of ethno-linguistic composition of daily activity districts in terms of forming interethnic relationships was also found for both of the ethno-linguistic groups which were included in the study (**Article II**). The higher percentage of residents in residential districts from another ethno-linguistic group is something which is related to having more interethnic networks formed in the first place. There is a positive correlation ($r=0.66$; $p<0.05$) between the percentage of Estonian-speakers who have an interethnic network and the share of Russian-residents in residential districts (Figure 9). For Russian-speakers, the proportion of people who have an interethnic network is higher when their residential districts contain less Russian-speaking residents ($r=–0.32$; $p>0.05$). The same finding is confirmed when using the binary logistic regression model, both for the ethno-linguistic composition of one's place of residence and workplace, and also when the effect of other characteristics (such as personal socio-demographic characteristics, or the number of call activities and calling partners) can be monitored

and checked (Models 1–3 in **Article II**). Both studied ethno-linguistic groups which are living in Tallinn are found to have a higher proportion of co-ethnic networks rather than interethnic networks. In total, 90 percent of Estonian-speakers and 65 percent of Russian-speakers have co-ethnic networks (**Article II**).

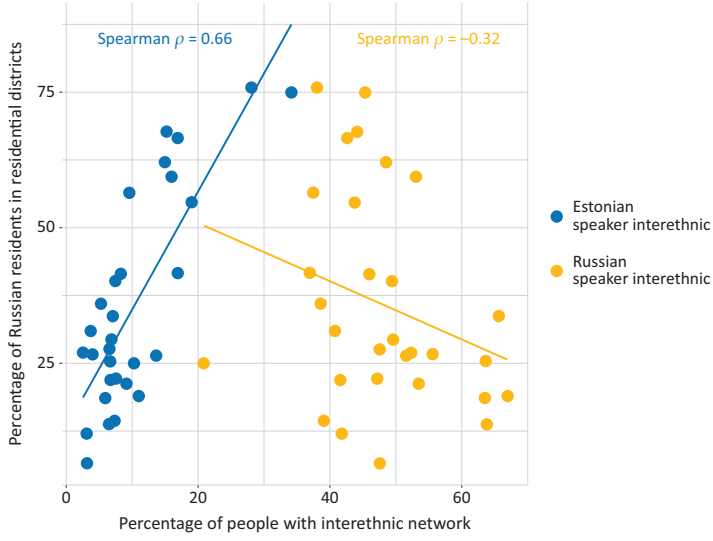

Figure 9. Correlation between the share of individuals with interethnic networks and Russian residents in residential districts. Source: Figure 3 in **Article II** (Silm et al, 2021).

5. DISCUSSION

Networks both in terms of theory and method have been increasingly used in various fields of research (Borgatti et al, 2009) to be able to understand these increasingly more complex and networked societies (Castells, 2010; Wellman, 2001). These analyses of networks have also become even more reachable due to the digital traces being left behind by people who are using ICTs, such as mobile phones (Masso et al, 2020; Watts, 2007). Despite the increased levels of recognition, there are still areas of research in which the full potential of networks has not yet been applied. In the field of human geography, in which the analysis of spatial mobility has been one of the main points of focus (for instance, see Ahas et al, 2010; Järv et al, 2015), there remains a lack of knowledge in terms of its connections with personal social networks. This thesis therefore takes a step forwards in this field whilst setting out a focus on the relationships which exist within it, with the aim of being able to highlight fresh insights into the use of mobile phone data. The main focus of the three articles which are included here has been on an investigation of the spatiality of personal social networks and spatial mobility. Even more, there are various characteristics which have been incorporated into the work which can be related to individuals, their networks, the use of ICTs, and daily activity locations, when it comes to being able to explain how these relationships are formed. To further illustrate the importance of studying these connections, the field of ethnic segregation has also been used as an example. The study of networks in this area provides a new nuance to the study of segregation as a whole.

Those results which are related to the general trend between personal social networks and spatial mobility are uniform in all three publications which have been included here: more spatially dispersed networks relate to more spatial mobility. This finding is in line with previously conducted studies which connected individual activity spaces with the spatial distribution of calling-partner networks (e.g., see Cho et al, 2011; Phithakkitnukoon et al, 2012). As the causality of the relationship was not fixed within the context of this thesis, the outcome can be explained in both directions. More spatially mobile people may have greater opportunities to create relationships on a geographically broader scale (for instance, see Calabrese et al, 2011; Sharmeen et al, 2015). In turn, already-existing relationships motivate individuals to travel to maintain these relationships and to gain support and well-being (e.g., see Carrasco & Miller, 2006; Larsen et al, 2006).

Connections between personal social networks are not uniform when they are studied through the use of a typological approach (**Article III**). When a smaller group of individuals were studied who were living and working or studying in the city of Tartu, three types emerged based on the spatial distribution of networks and spatial mobility: Type A with spatially dispersed networks and high mobility; Type B with spatially dispersed networks and low mobility; and Type C with concentrated networks and low mobility. While Type A and Type C reflect the general trend, with more dispersed networks relating to more mobility, Type B

shows that not all individuals are as spatially mobile in relation to their more spatially-extensive networks. This finding can be linked to different strategies in terms of organising and managing personal social networks over distance (e.g., see Cachia & Maya-Jariego, 2018; Saramäki et al, 2014). Type A subjects who are more mobile in relation to their dispersed networks are also found to have a higher share of network members with whom the most common meeting location is in partner homes, when compared to those who are less mobile (**Article III**). The latter further confirms the importance of visiting more spatially-dispersed personal networks. The missing type with a more concentrated network and high levels of mobility also confirms the higher levels of spatial mobility which should mainly be connected to personal social networks. This result can at least partially be explained by participants who are living and conducting other daily activities in the same university city, with previous studies here having shown that a higher population density and good access to services tends to decrease the need to travel outside the city for other purposes (de Vos & Witlox, 2016; Scheiner & Kasper, 2003).

The differences in the relationship between the spatial distribution of networks and spatial mobility can first be explained through personal characteristics, in which the shaping effect of gender (**Articles I, III**) and ethnicity (**Articles I, II**) were found to be the most prominent factors. In relation to gender, men tend to be more mobile in relation to their spatially-distributed networks, while women are less mobile. This was found by studying general relationships (**Article I**), and was further confirmed through the created typology (**Article III**). Men are found to have higher odds of belonging to Type A, with spatially dispersed networks and high levels of mobility, while women belonged to those types which had lower levels of mobility (types B and C). These results refer to more limited spatial mobility behaviour for women when they are compared to men, and falls in line with previously-conducted studies. Men have been found to have more spatially-dispersed networks (Kowald et al, 2013): they are spatially more mobile (Chakrabarti & Joh, 2019; Silm et al, 2013), and tend to conduct more social activities in general (Carrasco & Miller, 2006). These results have often been explained by the different societal roles being played by women, including raising children (Palchykov et al, 2012; Silm et al, 2013), but also by the gender pay gap and less car use (Chakrabarti & Joh, 2019; Cristaldi, 2005; Hamilton, 2001). The fact that Type B with spatially dispersed networks tend to consist more of women can also be explained by them retaining contacts in their place of origin, since women have been found to live further away from that location (Viry, 2012). Women tend to retain greater levels of diversity in their familial ties across their networks (Moore, 1990), and have different social strategies for relationship management across their lifespan (Palchykov et al, 2012).

Ethnicity is serving to shape the relationship, one in which the Russian-speaking minority in Estonia is found to have spatially more concentrated networks and spatial mobility when it is compared to that of the Estonian-speaking majority (**Articles I, II**). Those areas which Russian-speakers are visiting are more concentrated towards areas which have a higher share of Russian-speaking residents,

usually towards eastern parts of Tallinn and, on a broader scale, towards the northern and eastern Estonian regions (**Article II**). A good many mobility studies which have been conducted within the context of Estonia have highlighted the finding that there are more spatially constrained activity spaces for Russian-speakers (e.g., see Järv et al, 2015; Silm et al, 2018). The thesis additionally indicates the higher spatial concentration of personal social networks for Russian-speakers (**Article I**). For both ethno-linguistic groups, the more geographically-extensive personal networks are found to be related to more extensive mobility behaviour, in which no differences tend to emerge when two groups are being compared (**Articles I, II**). Therefore, having more spatially extensive networks in Estonia can similarly be related to more extensive spatial mobility for both Estonian-speakers and Russian-speakers.

More use of ICTs in this thesis has been found to be related to more spatially extensive networks, but not necessarily to more spatial mobility (**Article III**). Two types with spatially more dispersed networks (A and B) have been found to have higher levels of use of mobile phones in terms of the length of calls with a partner and the higher frequency of social media usage when compared to Type C which has more concentrated networks. For Type A, with its dispersed networks and high levels of mobility, the higher use of ICTs may be related to more mobile lifestyles which require the use of ICTs to organise the personal networks within those lifestyles and with activities on the move (Kwan, 2007; Yuan et al, 2012). For Type B with its dispersed networks and low levels of mobility, the use of ICTs and social media may be used as a way of compensating for and replacing physical mobility (Tillema et al, 2010). When the bigger networks of calling partners in their size were found to be related to more extensive spatial behaviour, differences were also visible in terms of the strength of the connection in relation to gender and ethnicity (**Article I**). This again indicated that even when women and Russian-speakers may have as big a calling-partner network as men and Estonian-speakers, they still tend to have spatially more concentrated activity spaces.

The role composition is also found to be important in terms of explaining the spatial distribution of personal social networks when it comes to the share of family members in personal networks. The results show that Type A and Type B subjects with their spatially dispersed networks have more family members in their networks than do Type C subjects with their more concentrated networks (**Article III**). These findings are based on mobile phone-based data, with them falling into line with previous studies which use more traditional methods (Carrasco et al, 2008; Carrasco & Miller, 2006). Namely, people tend to maintain long-distance relationships with close family and friends while, at the local level, there is a higher variety of role relationships. Weaker relationships tend to be less stable and are usually replaced by new local level relationships when place of residence or other daily activity locations change (Ryan, 2007; Saramäki et al, 2014; Visser et al, 2014).

The ethno-linguistic composition of personal networks is found to be related to the extent and ethno-linguistic composition of activity space (**Article II**).

Russian-speakers who have interethnic networks can be tied together with having more extensive activity spaces, in which visiting districts tend to consist of a lower average share of Russian-speaking residents when this figure is compared to Russian-speakers who have co-ethnic networks. The outcome is entirely the opposite for Estonian-speakers. For them, having an interethnic network relates to less extensive activity spaces and to visiting areas which have a higher share of Russian-speaking residents when compared to Estonian-speakers who have co-ethnic networks. These results can at least be partially explained by the language barrier, which may lead individuals who have co-ethnic networks to move more frequently in areas which have higher share of others who possess the same ethno-linguistic background. For Russian-speakers, it may also be the case that better levels of proficiency with the Estonian language gives them better opportunities to be able to participate in society, and with that also taking place on a larger spatial scale. This type of movement between the same linguistic space can be found in many mobility studies (e.g., see Mooses et al, 2020), but also when the share of mobile communications between different areas can be measured to show the stronger connection between areas which have the same linguistic space (e.g., see Expert et al, 2011).

Although there were no causal effects to be considered in the analysis for this thesis, the ethno-linguistic composition of networks can also be tied to a discussion of social capital. Having an interethnic network for Russian-speakers may give them better access to information, resources, and more diverse activity locations. Limited contact with a majority population, in turn, can often be related to imperfect participation in society (DiMaggio & Garip, 2012; Marques, 2012), and a resultant degree of socio-spatial isolation (Lee & Kwan, 2011), especially for Russian-speakers who have co-ethnic networks. Despite the knowledge that social relationships which are of different levels of strength and affiliation are linked to individual quality of life and achievements (DiMaggio & Garip, 2012; Granovetter, 1973), interethnic networks which are possessed by Estonian-speakers can be related to a lower use of space. This, in turn, can also be related to the spatial distribution of their, at least partially, Russian-speaking networks which are often concentrated in concrete areas due to the high levels of segregation in Estonia. As has also been found through the analysis which was conducted for this thesis, having personal social network members who live in areas which have a higher percentage of Russian-speaking residents means that more visits tend to take place into districts into which the average share of Russian-speaking residents is higher (**Article II**).

Living and working in areas which have a higher share of people who come from other ethno-linguistic groups can be linked to a higher tendency to form interethnic networks. The connection between living in areas which have a higher share of Russian-speaking residents and being in possession of interethnic networks is even stronger for Estonian-speakers than it is for Russian-speakers (**Article II**). This outcome is related to other studies which have shown that living and working in the same neighbourhoods as other ethnic groups serves to increase contact between those groups, and results in more interethnic ties being formed

(Eisnecker, 2019). Both Estonian-speakers and Russian-speakers who are living in Tallinn were found to form more homogeneous networks in terms of ethno-linguistic background, with 90 percent of Estonian-speakers having co-ethnic networks and 65 percent of Russian-speakers having them. This outcome strongly indicates homophily, in which culture and language continue to be important, leading to the process of interacting and forming relationships with others who have the same ethno-linguistic background (Kossinets & Watts, 2009; McPherson et al, 2001). This outcome is further enforced by the continuing spatial ethnic segregation in Estonia, not only at the level of neighbourhoods (Mägi et al, 2016), but also in kindergartens and schools (Masso & Soll, 2014), as well as in the workplace (Tammaru & Kulu, 2003), in leisure time activity locations (Kukk et al, 2019), and even in activity spaces as a whole (Järv et al, 2015; Silm et al, 2018). As has been found by others, such segregation has been found to remain relatively stable across generations (Silm et al, 2018), and this segregation continues along ethnic lines (Vihalemm, 2007). For Russians-speakers who have co-ethnic networks and who live and are mobile within areas which have higher shares of Russian speaking residents, this makes it hard for them to break out of these vicious circles of segregation (Krysan & Crowder, 2017; van Ham et al, 2018). With Estonian-speakers tending to have a greater number of co-ethnic networks, this could also reflect their wider choice of potential network members within the same ethnic group within Estonia, as it is this general group which forms the majority population. The limited interactions between minority and majority population groups cannot therefore be viewed only from the perspective of minorities. As has been found in previous studies, people with a higher socio-economic status are often those who tend to self-segregate themselves from minorities and people of a lower status (Priest et al, 2014; Wang & Li, 2016; Yip et al, 2016).

Living and working in minority-rich areas is also found to be related to having spatial mobility concentrated in areas in which the shares of Russian-speakers are higher, and for both ethno-linguistic groups in Tallinn (**Article II**). Since Estonian-speakers who have interethnic networks tend to be less mobile than those who have co-ethnic networks, this outcome can also be at least partially explained by the overlap between ethnic and socio-economic segregation (Järv et al, 2021). Lower socio-economic status is often related to having less spatially-extensive mobility (Carrasco & Miller, 2006; Tillema et al, 2010; van den Berg et al, 2012). For Estonian-speakers, the constant interactions in residential areas in which the share of Russian-speaking residents is higher can be related to less prejudice and more trust towards Russian-speakers, something which has been found to increase contact between different social groups (Grossetti, 2005; Heizmann & Böhnke, 2016).

Finally, the connection between the spatial distribution of networks and the extent of activity space is found to be stronger for individuals who are living in areas which have a higher population density such as the capital city, along with its commuting areas and regional centres (**Article I**). In turn, the connection is at its lowest levels for people who are living in small towns and rural areas. This

finding is similar to that by Phithakkitnukoon et al (2012), who found within the context of Portugal that the activity locations and network members of an individual are more spatially-concentrated when the individual concerned lives in densely-populated areas. These outcomes can be further explained by the opportunities being provided by different areas. People who live in sparsely-populated areas are often forced into mobility activities due to services which, and other individuals who, are accessible through spatial mobility (Meurs & Haaijer, 2001; Scheiner & Kasper, 2003; van den Berg et al, 2013). Having a workplace which is a greater distance away from home similarly affects connections, with longer distances leading to a weaker connection between the spatial distribution of networks and spatial mobility (**Article I**). This may further explain the lack of a study type, in terms of concentrated networks and high spatial mobility, in which study subjects worked and lived within the same city environment (**Article III**). Therefore those types of individuals who have more concentrated networks and greater levels of mobility may more probably be the case for individuals who live in less dense areas.

There were also many characteristics which have been included in these studies which did not remain significant enough to be able to explain the forming of connections between personal social networks and spatial mobility. Firstly, the life cycles and the person's age were expected to be significant when this area of examination was based on theory, with people tending to contribute to different relationships and activities at certain life stages (Masso et al, 2019; Wrzus et al, 2013). Even when the expected differences between students and staff members at the university were examined (**Article III**), still no differences could be found. Therefore age and life stages do not appear to affect the links between the spatial distribution of networks and spatial mobility, although this area of research certainly requires further exploration in future studies. The presence of children under the age of 18 was also not important (**Article III**), which can be explained primarily by gender, with women contributing more towards raising children (Palchykov et al, 2012; Silm et al, 2013). The income was similarly not as important as was expected (**Article III**), but it can be explained by potential support and resources being provided not by household members but through a variety of relationships which form part of personal networks. The insignificance of several of these indicators, such as income and the presence of children, can also be explained by the smaller group of subjects being studied in **Article III**, which may have provided different results from those which could have been gained if larger samples had been studied.

Those studies which were conducted as part of this thesis served to confirm the already-extant body of knowledge which was found through the existing personal network and mobility studies, such as the important role of personal networks in terms of individual activity-travel behaviour which had been confirmed by a study of general relationships (**Articles I, II, III**), along with the connection between the role composition of the network and its spatial distribution (**Article III**), as well as, firstly, by women (**Articles I, III**) and, secondly,

by ethnic minorities being spatially less mobile and having spatially more constrained activity spaces (**Articles I, II**). When compared to such studies which made use of more traditional methods (such as surveys, and interaction diaries) (for instance, see Carrasco & Miller, 2006; Tillema et al, 2010), those mobile phone-based studies which were conducted as part of this thesis made it possible for us to understand individual socio-spatial behaviour by including longer time periods and more complex geographical measures so that an understanding could be gained in terms of the spatial distribution of networks and spatial mobility.

While human geographers have been widely studying individual spatial mobility with the use of mobile phone-based datasets, and searching out differences based on individual level characteristics, such as gender, age, and ethnicity (e.g., Järv et al, 2015; Masso et al, 2019; Silm & Ahas, 2014), this thesis has added the dimension of personal social networks to the existing mix. When compared to other studies which generally tend to seek out general laws and trends based on mobile phone data (e.g., Fan et al, 2017; Onnela et al, 2011; Phithakkitnukoon et al, 2012), the three articles of this thesis have additionally explored the role of characteristics where they are related to an individual, along with the use of ICTs, network composition, and daily activity locations, by providing a more comprehensive understanding to how connections are formed between personal networks and spatial mobility (**Articles I, II, III**). Moreover, the use of a typological approach made it possible to study internal diversity in relationships while also connecting together the spatial distribution of networks and spatial mobility. To the author's knowledge, is the first such typology to have been based on both of these phenomena, and to have been compiled at the domestic level (**Article III**). A major contribution is also being made here in terms of understanding spatial ethnic segregation in Estonia. Studies have contributed to the existing depth of knowledge by including the measure of personal networks, which itself has been determined by connecting the available knowledge in terms of activity space to the understanding of spatial distribution and the ethno-linguistic composition of personal networks (**Articles I, II**).

ICT-based data has many strengths which make it possible for today's more complex society to be measured and, therefore, understood more effectively. Mobile phone data allows us to study actual interactions and locations from a large number of phone users, and over a large spatial scale, and even over longer study periods, while also being free of self-reporting. Datasets which have been collected via smartphone applications allow us to gather together an even richer set of data from smaller groups of individuals with the use of additional data collection methods. One example of this is information which was collected regarding the most important calling partners, by means of the survey which was based on call activity information (**Article III**), which acted like a name generator (for instance, see Tillema et al, 2010). In relation to network members who have been captured by the mobile phone data, there are also some limitations in this process since, nowadays, people use numerous ICT tools and channels for communications (Licoppe & Smoreda, 2005). However, those networks which are based on the most important calling partners are found mainly to consist of close

family members and friends with whom people also interact on a more physical basis (**Article III**). This finding confirms that people are still likely use mobile phones to communicate with close members of their networks (Ling, 2008), and that mobile phone-based data makes it possible to capture one's close, important network, something which is crucial regarding individual outcomes such as social activities and travel (for instance, see Carrasco et al, 2008). In further studies for the future, the overlap between networks which have been captured by ICTs and those which are perceived by individuals would be able to provide an important area of input in terms of being able to understand precisely who is not being captured by these ICT-mediated networks.

The use of mobile phone data enables us to study a broad variety of topics. In the current thesis, a study was carried out regarding relationships between personal social networks and spatial mobility, with a special focus on ethnicity, but it should be regarded as important to further investigate the other possible existing inequalities, such as those which may arise from gender. In relation to ethnic segregation and the ethno-linguistic composition of networks, it should be of interest to study not only individuals who are living in Tallinn, but also those who are living in the northern and eastern Estonian regions, with those areas being dominated by Russian-speakers, and where such relationships may manifest themselves differently. It is also crucial to further understand how the typologies may manifest themselves on a broader spatial scale since the typological approach in this thesis was applied only to study subjects living and working or studying in the same city context (**Article III**). Additional important areas of knowledge could be provided by information which is related to spatial relocations or life cycle events, which have been seen as being crucial in coming to an understanding about the dynamics behind relationships (for instance, see Fudolig et al, 2021; Sharmeen et al, 2015), while also enabling the inclusion of more causal effects into these analyses. Data which has been collected via smartphone applications such as MobilityLog also provides new opportunities for further research, for which the inclusion of more traditional data collection methods such as surveys and interviews are useful in terms of being able to understand the real reasons behind simple numerical figures. The inclusion of network theories such as homophily may also further serve to bring about an understanding in terms of probable conflicts, prejudice, and attitudinal measures from the viewpoints of different groups in society (such as socio-economic or ethnic viewpoints). These areas of understanding are important to understand these increasing divides more fully within existing societies.

It should also be borne in mind that the period which was under study in this thesis reflects the time prior to the arrival of COVID-19. Gaining an understanding of personal social networks, interactions within networks, and spatial mobility is therefore even more crucial today, with these playing such a central role in the spread of viruses (Block et al, 2020; Scala et al, 2020; Tizzoni et al, 2014). Restrictions which have been set out both in terms of physical interaction and mobility during the COVID-19 pandemic have already been seen to increase already existing social inequalities and divides within societies. It is crucial to

assess how different people perceive these constraints and the extent to which their daily interaction patterns are reshaped both physically and through using ICTs. As a highly interdisciplinary field of study, the more general goal of this thesis is to encourage collaboration between researchers in different fields of science. This allows us to see beyond existing approaches to uncover new perspectives in the discovery of connections between the phenomena.

6. CONCLUSIONS

We live in a networked society where, in addition to the physical mobility, communications which are mediated by ICTs are also central. It increasingly requires an inclusion of networks as a theory and method to understand these networked connections. The aim of this thesis was to gain new depths of knowledge about relationships between personal social networks and spatial mobility, which are two central phenomena in people's lives. So far, these relationships have been studied through a number of field-specific approaches, which have been based either on traditional data collection methods or on data collected through the use of ICTs. The current thesis combined this previous knowledge to better understand personal social networks and spatial mobility, in which the latter is one of the main interests in the field of human geography. This thesis is based on two types of mobile phone data, where the first is collected by mobile network operators and the second through a smartphone application. The research carried out within the framework of the thesis focused on these relationships within the Estonian context, covering different periods between 2013–2017.

All studies which were carried out for this thesis confirm the significant link between personal social networks and spatial mobility. Through the analysis of the spatial distribution of personal social networks and spatial mobility, a general trend has emerged in all three articles: spatially more-dispersed networks are related to greater spatial mobility. The typology created while studying the group of people who were living in Tartu and who were studying or working at the university highlighted three types: dispersed networks and high mobility (Type A); dispersed networks and low mobility (Type B); and concentrated networks and low mobility (Type C). While Type A and Type C fall into line with the general trend, Type B shows that not all individuals are as spatially mobile in relation to their spatially-extensive networks. The missing type with its spatially concentrated networks and high mobility even further confirms the importance of personal networks in relation to spatial mobility.

Gender and ethnicity were found to be the most significant personal characteristics shaping relationships between the spatial extent of the networks and spatial mobility. Men are found to be more mobile in relation to their spatially-dispersed networks. Men were more likely to belong to a group (Type A) which had spatially dispersed networks and high mobility. Women were more likely to belong either to Type B or Type C, being spatially less mobile in both cases, even if their personal network was more spatially extensive. A different relationship was found in the evaluation of Estonian-speakers and Russian-speakers. Although networks of Russian-speakers are spatially more concentrated, having spatially more extensive personal networks was similarly related to more spatially-extensive mobility for both language groups.

The use of ICTs and role composition are related primarily to the spatial distribution of personal social networks. Type A and B individuals, who have spatially more extensive networks but who differ in terms of their spatial mobility, can

both be found to use more ICTs. These spatially more extensive networks also consist of a higher share of family members. Belonging to Type C with its concentrated networks and low mobility is related to less use of ICTs and a lower share of family members in their networks. Thus, the wider use of ICTs cannot always be associated with greater mobility, and family networks must be seen as important in the formation of spatially-extensive networks.

The ethno-linguistic composition of networks is related to the spatial extent of the activity space. A study of two ethno-linguistic groups who were living in the capital city of Tallinn found that Russian-speakers who had interethnic networks had spatially more extensive activity spaces than did Russian-speakers who had co-ethnic networks. For the latter, their activity spaces are the most spatially-concentrated, especially towards minority-rich areas such as the eastern parts of Tallinn and, on a broader scale, towards the northern and eastern Estonian regions. The outcome is the opposite for Estonian-speakers, where having an interethnic network is related to less extensive activity spaces when compared to Estonian-speakers who have co-ethnic networks and who have most geographically-extensive activity spaces. These results can be linked, for example, to the wider debate on socio-spatial segregation, attitudes and language proficiency, and the social capital provided through interethnic networks.

Living and working in areas which have a higher level of exposure to other ethno-linguistic groups were also found to explain the formation of interethnic networks. There is a higher tendency to have interethnic networks when the share of residents from another ethno-linguistic group is higher. Among both Estonian-speakers and Russian-speakers, more individuals who have co-ethnic networks were found. The percentage of individuals who have co-ethnic networks is higher amongst Estonian-speakers (totalling 90 percent) than it is for Russian-speakers (65 percent). The formation of ethno-linguistically homogeneous personal networks can thus be associated with the continuing spatial ethnic segregation in Estonia, and that not only at the level of residential neighbourhoods, but also in other everyday settings such as schools or workplaces.

Studies which cover mobile phone users living across the country also found differences in living at different levels of the settlement-system hierarchy. Stronger links between the spatial distribution of networks and the spatial extent of one's activity space appeared for individuals who were living in more densely populated areas such as the capital city or regional centres. The links were weaker when people were living in less densely populated areas, such as small towns and rural areas, which raises new questions about the accessibility and opportunities provided by these different settlements.

The importance of this thesis lies in its ability to look beyond general laws and trends. When compared to other mobile phone data-based studies, this thesis has been able to include the various characteristics of an individual, along with the use of ICTs, the composition of the network, and daily activity districts, making it possible to further explore these emerging links. Unlike traditional approaches, mobile phone-based studies are able to include geographical measures and longer time periods, thereby providing more a comprehensive picture when it comes to

being able to understand these relationships. The thesis presents a typology which, to the author's knowledge, is the first approach towards domestic-level connections between the spatial distribution of networks and spatial mobility. For human geographers who are interested in spatial mobility, the thesis creates a stronger connection with personal social networks, and that also through the established theoretical framework. A great contribution has also been made in reaching a better level of understanding of ethnic segregation within the Estonian context, serving to link existing knowledge on the spatial behaviour of ethnic groups with the spatial distribution of networks and its ethno-linguistic composition.

The results of the thesis highlight the need for a better understanding of networks to gain new knowledge of the causes which lie behind phenomena both social and spatial in nature. Studies which were carried out for this thesis helped to map out the situation which prevailed prior to the advent of the COVID-19-related crises and the resultants imposition of restrictions. Since both personal social networks and spatial mobility are central to understanding the spread of viruses, studies which serve to connect these two phenomena are expected to increase in the near future. Knowledge in this area is vital for crisis management, but also in terms of being able to understand the effect of new policies on social lives and routines, where significant changes are required to be made by individuals. Therefore the approach to networks and the interlinked methods are important as this will provide a potential common language and opportunities for cross-disciplinary study.

ACKNOWLEDGEMENTS

The study of personal social networks is fascinating not only due to its scientific value, but also due to the better ability to acknowledge all the people who have led me to this point of life.

Firstly, I would like to acknowledge my personal network established during my studies in University of Tartu. My journey in doctoral level of studies would have not been started without professor Rein Ahas and my supervisor Siiri Silm who kindly offered me the opportunity to delve deeper into the world of science. I really do appreciate it. At least as much acknowledgement goes to my other supervisor Anu Masso who gave at least as significant input to the completion of my studies. I thank both of my supervisors for their time, joint discussions, and forward-looking ideas.

The academic life is not as good without the people with whom it is shared a daily basis. I would like to acknowledge many of my past and present colleagues. My special thanks go to my colleagues in MobilityLab: Kristi, Veronika, Janika, Laura, Anto, Age, Mirjam, Ago, Pilleriine, Arvi, Erki and Margus. You have all proved that together it is possible to overcome even the most difficult times when everything seems to fall apart.

I've been also expanding my personal network through my academic journey and that not only in its size, but also by its geographical reach. Through my travels both near and far (e.g., Austria, Italy, Hungary, Romania, Belgium, United States, and China), I've met many great and fascinating people. These connections continue to exist and from time to time they lead to interactions and new opportunities for cooperation. I am especially thankful for the opportunity to be part of COST TU1305 project 'Social Networks and Travel Behaviour', where participating as a young researcher led me into contact with others with similar kinds of interests. I also appreciate all the contacts created in our very own Mobile Tartu conference I am happy to be part of organizing.

Finally, my rather large and close network of family members. My mother Jane and father Erik, who have been my main supporters through all my journeys. My grandparents and countless other relatives. Thank you for being my support network and by showing the importance of continuous selfless acts. The influence of my family is best described by where I am today. One phone call from my grandmother with a question: "Why not study Geography?" became decisive in my decision-making. Even more, my footsteps took me to my current workplace much earlier to visit either a natural museum as a kid or relatives who worked in the same building and even in the same rooms. The thesis is also a dedication to my grandfather Väino with whom the talks about academic life and life in general made me feel that I am in a right place and following the right path. And the most important ones. My partner Steven and my son Sten Erik – you are the two, where more of my attention and time should now go…

This work was supported by the institutional research grant (no IUT 2-17) of the Ministry of Education and Research of Estonia; Estonian Research Council

(no. PUT PRG306); the European Commission through the H2020 project ‘Finest Twins’ (no. 856602); the Estonian Science Infrastructure Road Map project ‘Infotechnological Mobility Observatory (IMO)’; the Archimedes Foundation through the ASTRA program (no. 2014–2020.4.01.16-0032 and no. 2014–2020.4.01.16-0027); the European Regional Development Fund via the Interreg Central Baltic Programme project ‘Campus Areas as Labs for Participatory Urban Design’. The acknowledgements also go to Mobile Network Operators and Positium LBS for the data, and Mattias Linnap for developing the MobilityLog app. I would also like to thank all the study participants whose activities have left behind these ‘traces’ needed to conduct all these studies.

SUMMARY IN ESTONIAN

Isiklike sotsiaalsete võrgustike ja ruumilise mobiilsuse seosed mobiiltelefonide andmetel

Keerulised ühiskondlikud struktuurid on alati eksisteerinud, kuid info- ja kommunikatsioonitehnoloogia (IKT) ja transpordi areng on muutnud kogukonnad veelgi keerukamateks võrgustikeks (Wellman, 2001). Kaasaegse ühiskonnavormi kirjeldamiseks, mis on kujunenud IKT võrgustike ümber, on kasutatud tihti ka mõistet "võrguühiskond" (Castells, 2010). Võrgustike analüüsi peetakse 21. sajandi teaduseks, et kõiki neid kiireid ühiskondlike muutusi ja keerulisi protsesse paremini mõista (Watts, 2007). Sellest tulenevalt on võrgustikke nii teooria kui ka meetodina üha enam rakendatud erinevates uurimisvaldkondades, sealhulgas sotsiaalteadustes (Borgatti et al, 2009). Mõningates uurimisvaldkondades on aga võrgustike rakendamine endiselt puudulik. Võrgustike kaasamise olulisuse esile toomiseks inimgeograafia valdkonnas, kus mobiilsuse analüüs on üheks põhifookuseks, lisab käesolev doktoritöö sellele seose isiklike võrgustikega. Nii isiklike sotsiaalsete võrgustike kui ka ruumilise mobiilsuse korral on tegemist kahe inimeste elus kesksel kohal oleva ja omavahel lahutamatult seotud nähtusega, mille tähtsus on viimastel aastakümnetel veelgi suurenenud (Axhausen, 2007). Inimesed on üha rohkem ühenduses ja tegutsevad distantsilt, olles samal ajal ka liikuvuses. Seeläbi on tegevus- ja reisikäitumine oluliselt ümber kujunenud (Kwan, 2007).

Isiklikke võrgustikke ja ruumilist mobiilsust ühendavate uuringute pidev kasv on täheldatav alates 21. sajandi algusest (Plaut & Schach-Pinsly 2009). Neid seoseid on uuritud erinevates teadusvaldkondades, nt transpordiuuringud, sotsioloogia ja füüsika. Võrgustike ja IKT kasutuse modelleerimist on kasutatud tegevusreiside vajaduse mõistmiseks (nt Carrasco & Miller 2006; Guidon et al, 2018). Need erinevad uuringud on kinnitanud isiklike võrgustike paiknemise ja koosseisu ning IKT vahendatud kommunikatsiooni olulisust tegevusreiside seisukohalt (nt Carrasco et al, 2008; Kowald et al, 2013). Olulisi täiendavaid teadmisi on saadud sotsiaal-ruumilise isolatsiooni ja juurdepääsetavuse mõistmisel, võimaldades hinnata ebavõrdsust (nt Carrasco & Cid-Aguayo, 2012; Lee & Kwan, 2011). Mõned uuringud on keskendunud ka teist tüüpi seostele, kus on kasutatud tüpoloogilist lähenemisviisi isiklike sotsiaalsete võrgustike paiknemise mõistmiseks seotuna ruumilise mobiilsusega (nt Cachia & Maya-Jariego, 2018), kuid sellise lähenemise kasutamine on pigem vähene. Kõik need uuringud on kasutanud traditsioonilisi andmekogumise meetodeid, näiteks küsitlusi, intervjuusid ja reisipäevikud.

Samaaegselt on suuri edusamme võrgustike ja ruumilise mobiilsuse analüüsis tehtud ka IKT-põhistele andmetele tuginedes. Inimeste igapäevane IKT-põhine suhtlus ja tegevused (nt mobiiltelefonide ja interneti kasutus) jätavad digitaalseid jälgi, mida saab rakendada erinevate ühiskondlike nähtuste analüüsiks (Masso

et al, 2020). Ühelt poolt sisaldavad need andmed informatsiooni inimeste omavahelise suhtluse kohta, kuid asukohapõhised IKT-d talletavad informatsiooni ka kasutajate ruumilisest paiknemisest (Blondel et al, 2015; Harrison et al, 2020). Mobiiltelefoni kõnetoimingute kirjed ja sotsiaalmeedia andmed on mõned näited nendest digitaalsetest jälgedest (Blondel et al, 2015; Grabowicz et al, 2014; Stopczynski et al, 2014). IKT andmeid on palju kasutatud arvutusteadustega seotud valdkondades (nt arvutiteadus, füüsika), et uurida seaduspärasid ja trende inimeste sotsiaal-ruumilises käitumises (nt Calabrese et al, 2011; Fan et al, 2017; Lazer et al, 2009; Shi et al, 2016). Võrgustikke ja ruumilist mobiilsust siduvates uuringutes on aga pigem vähem tähelepanu pööratud kas isikuomadustest või inimeste igapäevaste tegevuskohtade paiknemisest tulenevale varieeruvusele (nt Phithakkitnukoon et al, 2012). Mobiilisuhtluse intensiivsusele ja ruumilise mobiilsusele keskenduvad uuringud on leidnud, et suurem mobiiltelefoni kasutus on seotud ulatuslikuma ruumilise mobiilsusega, kuid on mõjutatud erinevatest tunnustest (nt Yuan et al, 2012). Seetõttu on vaatamata suurele arvule IKT-põhiseid andmeid kasutavatele uuringutele endiselt palju avastada. Oluliseks puudujäägiks on ka rohkem traditsiooniliste lähenemiste ja IKT-andmestikele tuginedes saadud teadmiste omavaheline vähene sidumine saamaks põhjalikemaid teadmisi nende seoste avaldumisest. Interdistsiplinaarse uurimisvaldkonnana on doktoritöö laiem eesmärk ergutada koostööd erinevate teadusharude vahel, mis võiks võrgustike analüüsi abil kaasa tuua edusamme erinevate sotsiaalsete protsesside ja probleemide kaardistamisel ja mõistmisel.

Doktoritöö eesmärk on saada uusi teadmisi isiklike sotsiaalsete võrgustike ja ruumilise mobiilsuse omavahelistest seostest ning seoseid mõjutavatest teguritest. Töö tugineb kolmele artiklile, mille raames neid seoseid mobiiliandmestikele tuginedes uuritakse. Uuringud katavad erinevaid ajaperioode aastatest 2013–2017, keskendudes seega perioodile enne COVID-19 pandeemiat, mil inimeste igapäevane füüsiline suhtlus ja ruumiline mobiilsus ei olnud piiratud. Töös on püstitatud järgmised uurimisküsimused:

1. Millised seosed on isiklike sotsiaalsete võrgustike ruumilise jaotuse ja ruumilise mobiilsuse vahel? (Artiklid I, III)
2. Kuidas kujundavad isikuomadused isiklike sotsiaalsete võrgustike ja ruumilise mobiilsuse seoseid? (Artiklid I, II, III)
3. Kuidas kujundab IKT kasutus isiklike sotsiaalsete võrgustike ja ruumilise mobiilsuse seoseid? (Artiklid I, III)
4. Kuidas kujundab võrgustiku koosseis isiklike sotsiaalsete võrgustike ja ruumilise mobiilsuse seoseid? (Artiklid II, III)
5. Kuidas kujundavad igapäevaste tegevuspiirkondade omadused isiklike sotsiaalsete võrgustike ja ruumilise mobiilsuse seoseid? (Artiklid I, II)

Doktoritöö uurib neid seoseid Eesti kontekstis, andes põhjaliku ülevaate erinevatest omadustest, mis kujundavad seoseid isiklike sotsiaalsete võrgustike ja

ruumilise mobiilsuse vahel. Töö keskendub Eestis elavatele võrgustike liikmetele ja siseriiklikul tasandil ruumilisele mobiilsusele. Töös on pööratud erilist tähelepanu ka võrgustikele ja ruumilisele mobiilsusele läbi etnilise segregatsiooni vaatenurga, kus erinevate rahvusrühmade ruumiline käitumine on üks oluliseim ebavõrdsuse kujundaja Eestis (nt Järv et al, 2015; Mooses et al, 2016; Mägi et al, 2016; Silm et al, 2018).

Doktoritöö tugineb kahte tüüpi mobiiltelefonide andmestikele: mobiilioperaatorite kõnetoimingute andmed ja kõnegraafi andmed, mis salvestatakse automaatselt mobiilioperaatorite logifailidesse kõne toimumisel. Kõnegraafides on pseudonüümsed identifitseerimiskoodid (ID) nii kõnetoimingu algatanud kui ka kõnetoimingu vastu võtnud mobiilikasutaja kohta, samuti aeg, mil kõne toimus. Asukohtade informatsioon on kogutud väljuvate kõnetoimingutega ühendunud antenni täpsusega. Need andmed on laiemalt tuntud ka kui passiivse mobiilpositsioneerimise andmed (Silm et al, 2020). Nii kõnegraafid kui ka asukohad on seotavad unikaalsete ID-de abil, mis ei võimalda aga siduda andmeid isiku või tema telefoninumbriga, tagades mobiilikasutajate anonüümsuse (Saluveer et al, 2020). Teaduslikel eesmärkidel on töös kättesaadavaks tehtud ka informatsioon inimese soo, sünniaasta ja eelistatud suhtluskeele kohta. Iga mobiilikasutaja elu- ja töökoha määramiseks on kasutatud ankurpunktide mudeli metoodikat (Ahas et al, 2010), mis põhineb kõnetoimingute ajastusel ja asukohal. Artikkel **I** uuris enam kui 70 000 mobiilikasutajat 2013. aasta veebruaris, kelle elukohad asusid üle Eesti. Artikkel **II** kaasas üle 13 000 Tallinnas elava mobiilikasutaja andmeid 2016. aastal.

Teist tüüpi mobiiltelefonide andmestik on kogutud nutitelefoni rakendusega MobilityLog, mis on loodud pikaajaliseks mobiilsuskäitumise uurimiseks ja sotsiaalse võrgustikuga seotud analüüsideks. Rakendus on arendatud Mattias Linnapi ja Tartu Ülikooli mobiilsusuuringute labori koostöös (Linnap & Rice, 2014; Poom, 2019). Töös kasutatakse esmalt rakenduse poolt kogutud kõnetoimingute metaandmeid ehk kõnegraafe, mis sisaldavad detailsemat informatsiooni inimeste kõnetoimingute kohta, sisaldades näiteks ka nende tüüpi (telefonikõne, sõnum) kui kestust. Asukohad on kogutud rakenduses GPSi abil, kus tegevuskohtade tuvastamiseks on analüüsitud GPS andmetest tuletatud "peatusi" – rühmitatud GPS punktid, mis tuginevad punktide omavahelisele kaugusele ja ajale (Poom, 2019). Uuringusse on kaasatud andmed ajaperioodist august 2016–juuli 2017 ning uuritavaid oli kokku 80, neist ülikooli töötajad 51% ja üliõpilased 49%. Kõikide uuritavate elu- ja töökohaks oli uuritaval perioodil Tartu. Kõik uuringus osalejad allkirjastasid teadliku nõusoleku uuringus osalemiseks. Lisaks mobiilirakendusega kogutud andmetele täiendati andmeid näost-näkku küsitlusega, mille raames koguti ka informatsiooni nii inimeste sotsiaaldemograafiliste tunnuste kui ka IKT ja sotsiaalmeedia kasutuse kohta. Töös on kasutatud ka sama küsitluse abil kogutud võrgustike andmeid, mis tuginesid otseselt kogutud kõnetoimingute andmetele. Osaliselt pseudonüümsed (kolm numbrit asendatud) kõnepartnerite numbrid võimaldasid koguda informatsiooni kümne kõige olulisema kõnepartneri kohta. Partnerite olulisus on määratud kõnetoimingute vastastikususe (üks sisenev ja üks väljuv kõnetoiming) ning kõnetoimingute arvu alusel.

Need partnerid moodustasid võrgustiku, mille kohta koguti järgnevad andmed: partnerite elukoht, partneri roll, lähedusaste, näost-näkku kohtumiste sagedus, kõige olulisem ühine kohtumiskoht.

Mobiiliandmete kasutamiseks ja sellest sisulise informatsiooni leidmiseks kasutati erinevaid lähenemisviise, mis võimaldasid nii võrgustikku kui ka inimese ruumilist mobiilsust määratleda. Inimeste isiklikke võrgustikke on vaadatud üksikisiku vaatenurgast, kus uuritakse kõiki nendega otseselt seotud kõnepartnereid. Vastastikuse kõnetoimingu tingimus võeti aluseks kõigis kolmes uuringus, et välistada vähemolulised ühesuunalised numbrid, mis sageli esindavad erinevaid müügikõnesid. Antud kriteeriumit on rakendatud ka teistes mobiiliandmestikel tuginevates ja võrgustikele keskenduvates uuringutes (nt Carron et al, 2016; Onnela et al, 2007). Mobiilioperaatorite andmestike võrgustikest kaasati kõik vastastikused kõnepartnerid, kelle vahel oli kõnetoiminguid uuringuperioodil. Võrgustikes olid olulisemateks nende ruumilise paiknemise tunnused: liikmete elukohtadega ruumiliste üksuste arv, elukohtade jaotuse mitmekesisus omavalitsuses ja keskmine kaugus võrgustike liikmete elukohtadeni uuritava elukohast. Kesksteks analüüsitud tunnusteks olid näiteks ka vastastikuste kõnepartnerite arv ja võrgustike etnilis-keelelisus. Inimeste võrgustikud on loetud üherahvuseliseks, kui kõik võrgustiku partnerid kasutasid sama suhtluskeelt kui uuritav mobiilikasutaja. Mitmerahvuseline võrgustik moodustus uuringus, kui vähemalt üks partneritest kasutas teist suhtluskeelt.

Ruumilist mobiilsust mõõdeti nii läbi tegevusruumi käsitluse kui ka läbitud vahemaade kaudu. Tegevusruumi ulatust mõõdeti uuringuperioodi jooksul külastatud ruumiliste üksuste arvu või tegevusruumi ellipsi pindalana. Tegevusruumi ellips on standardhälbe ellips (95%), mis tuleneb kõnetoimingute teostamise asukohtadest ja neis tehtud kõnede arvust. Lisaks kasutati tunnuseid nagu keskmine päevas külastatud omavalitsuste ja läbitud kilomeetrite arv; külastatud omavalitsustes viibimise mitmekesisus tuginedes neis veedetud päevade arvule. Tegevusruume kirjeldavateks mõõdikuteks olid ka vastavalt vene rahvusest elanike osatähtsus elu- ja töökohas ning keskmistatuna kõigis külastatud piirkondades. Võrgustike tunnuste seoste uurimiseks kasutati meetodeid, kus üldiste seoste analüüs tugineb Spearmani korrelatsioonianalüüsile. Samuti kasutati regressioonianalüüsi meetodeid (nt GLM, binaarne logistiline regressioon). Seoste mitmekesisuse uurimiseks kasutati lisaks lineaarsele lähenemisele ka k-keskmiste klasteranalüüsi.

Isiklike sotsiaalsete võrgustike ruumilise paiknemise ja ruumilise mobiilsuse seoste analüüsimisel ilmnes üldine trend: ruumiliselt hajutatud võrgustikud on seotud ulatuslikuma ruumilise mobiilsusega. Põhjuslikkuse suunda võrgustike ja mobiilsuse vahel töös ei määratletud ja seetõttu võib tõlgendada tulemusi kahes suunas: ulatuslikum mobiilsus suurendab võimalusi luua geograafiliselt ulatuslikemaid võrgustikke, kuid juba eksisteerivad võrgustikud on oluliseks reisikäitumise kujundajateks suhete säilitamise ja heaolu eesmärgil (nt Carrasco & Miller, 2006; Larsen et al, 2006; Sharmeen et al, 2015). Rakendatud tüpoloogiline lähenemisviis tõi aga esile, et kõik inimesed ei ole oma ruumiliselt hajutatud

võrgustikes ruumiliselt sama liikuvad. Tüpoloogia, mis tugineb Tartu linna uuritavate rühmale, näitas kolme eristunud tüüpi: (A) ruumiliselt hajutatud võrgustikud ja suur mobiilsus, (B) ruumiliselt hajutatud võrgustikud ja vähene mobiilsus ning (C) ruumiliselt kontsentreeritud võrgustikud ja vähene mobiilsus. Kui tüüp A ja tüüp C on kooskõlas eelpool toodud üldise trendiga, siis tüübi B esindajad on oma ruumiliselt hajutatud võrgustikus vähem liikuvad. Vähesem liikuvus antud tüübi korral võib viidata erinevatele strateegiatele isiklike võrgustike organiseerimisel ja juhtimisel (nt Cachia & Maya-Jariego, 2018; Saramäki et al, 2014). Uuringus ei tulnud esile ruumiliselt kontsentreeritud võrgustike ja suure mobiilsusega tüüpi, mis omakorda kinnitab olulist seost võrgustike geograafia ja ruumilise mobiilsuse vahel.

Võrgustike ruumilise ulatuse ja mobiilsuse vahelist seost mõjutavad inimeste tunnustest enim sugu ja rahvus. Meeste võrgustikud on hajutatumad ja nad on liikuvamad kui naised, seda kinnitavad seosed võrgustiku paiknemise ja ruumilise mobiilsuse tunnuste vahel. Mehed kuuluvad suurema tõenäosusega ka tüüpi A, mida iseloomustab võrgustiku ruumiline hajutatus ja suur mobiilsus. Naised on suurema tõenäosusega tüübi B või C esindajad, kes on mõlemal juhul ruumiliselt vähem mobiilsed olenemata võrgustiku hajususest. Soolised erinevused on kooskõlas varasemate uuringutega, mis toovad esile meeste ruumiliselt ulatuslikumad võrgustikud (Kowald et al, 2013), suurema ruumilise mobiilsuse (Chakrabarti & Joh, 2019) ja kalduvuse suuremale sotsiaalsele aktiivsusele võrreldes naistega (Carrasco & Miller, 2006). Sugude erinevusi on põhjendatud ka meeste ja naiste ühiskondlike rollidega (Palchykov et al, 2012; Silm et al, 2013) ning naiste väiksema sissetuleku ja autokasutusega (Chakrabarti & Joh, 2013; Cristaldi, 2005). Naiste ruumiliselt ulatuslikumaid võrgustikke võrreldes meestega selgitab ka kontaktide hoidmine varasema elukohaga (Viry, 2012) ja suurema arvu perekondlike sidemete säilitamisega (Moore, 1990). Eesti- ja venekeelsetes rahvusrühmades leiti erinev seos: kuigi venekeelsete inimeste võrgustikud on sarnaselt nende ruumilisele mobiilsusele rohkem kontsentreeritumad kui eestikeelsetel, siis hajusamad võrgustikud on seotud ulatuslikuma mobiilsusega mõlemas rahvusrühmas.

IKT-l on oluline seos eelkõige sotsiaalsete võrgustike paiknemisega, kuid ei ole tingimata seotud suurema ruumilise mobiilsusega. Rohkemate kõnepartneritega võrgustikud seostusid ruumiliselt ulatuslikuma mobiilsusega, kuid ka siin on erinevused sugude ja rahvusrühmade vahel. Andmed viitavad, et olenemata suurematest võrgustikest on naistel ja venekeelsetel rahvusrühmadel endiselt ruumiliselt rohkem kontsentreeritumad võrgustikud võrreldes vastavalt meeste ja eestikeelsete rahvusrühmadega. Tüüpide vaheliste erinevuste uurimisel leiti, et suurem IKT kasutus seostub eelkõige ruumiliselt ulatuslikemate võrgustikega, kus suurem IKT kasutus leiti tüüpi A ja B kuuluvatel uuritavatel. Võrreldes hajusamate võrgustike tüüpidega (A ja B) oli rohkem ruumiliselt kontsentreeritud võrgustikes päevased kõned lühemad ning sotsiaalmeedia kasutati harvem. Tüübi A korral saab suuremat IKT kasutust seostada näiteks mobiilsema elustiiliga, KT-d kasutatakse isiklike võrgustike korraldamiseks liikumises olles (Kwan, 2007; Yuan et al, 2012). Tüübi B (ruumiliselt vähem mobiilsed hajusas

võrgustikus) suurem IKT kasutus võib olla seotud füüsilise mobiilsuse kompenseerimise ja asendamisega (Tillema et al, 2010). Võrgustike ruumiline hajuvus on seotud ka perekonnaliikmete osatähtsusega võrgustikus, sest ruumiliselt ulatuslikumas võrgustikus on suurem perekonnaliikmete osatähtsus. See kinnitas varasemalt leitut, et inimesed säilitavad eelkõige lähedasemaid perekondlikke ja sõprussuhteid ja seda ka olenemata vahemaast (nt Carrasco et al, 2008).

Sõltuvalt võrgustiku eesti- või venekeelsetest partneritest, leiti seos nii tegevusruumi ulatuse kui ka rahvusrühmade esindatusega nende igapäevastes tegevuskohtades. Tallinna rahvusrühmade uurimisel leiti, et mitmerahvuselises võrgustikus venekeelsed on seotud ulatuslikema tegevusruumiga võrreldes samarahvuseliste võrgustikega venekeelsetega. Samarahvuseliste võrgustikega venekeelesete tegevusruumid olid kõige enam ruumiliselt koondunud ja seda eelkõige Tallinna idaossa ning laiemalt Põhja- ja Ida-Eestisse, kus venekeelsete elanike osatähtsus on suurem. Vastupidine ilmnes eestikeelsetel inimestel, kelle mitmerahvuselised võrgustikud olid seotud vastavalt väiksema tegevusruumiga võrreldes samarahvuseliste eestikeelsete võrgustikega. Samarahvuselisi võrgustikke moodustavatel eestlastel oli tegevusruum geograafiliselt kõige ulatuslikem. Põhjuseks võib olla keelebarjäär, kuna inimesed liiguvad rohkem sama keeleruumiga piirkondade vahel (nt Mooses et al, 2020). Mobiilisuhtluse mahtude uurimisel erinevate piirkondade vahel on leitud, et sama keeleruumiga piirkonnad on rohkem ühendatud (nt Expert et al, 2011). Venekeelsete inimeste mitmerahvuselised võrgustikud võivad seega väljendada ka nende paremat eesti keele oskust, mis loob paremad võimalused ühiskonnaelus osalemiseks ja seda ka ruumiliselt. Vähest kontakti enamusrahvustega on seostatud vähesema osalusega ühiskonnas (DiMaggio & Garip, 2012; Marques, 2012) ja sotsiaal-ruumilise isolatsiooniga (Lee & Kwan, 2011).

Erineva rahvusliku koosseisuga piirkondades on võrgustike entilis-keelelisel koosseisul seos ka elamise ja töötamisega. Mitmerahvuselise võrgustiku esinemise tõenäosus on suurem, kui elu- ja töökoha piirkonnas on teisest rahvusest elanikke rohkem. See tulemus ühtib varasemate uuringutega, kus sagedasem kontakt teiste etniliste rühmadega elu- ja töökoha piirkonnas suurendab sidemete moodustamist erinevate rahvuste vahel (nt Eisnecker, 2019). Samas nii eesti- kui ka venekeelsetel on rohkem samarahvuselisi võrgustikke, see on suurem eestikeelsetel (90%) kui venekeelsetel (65%), mis on selgitatav homofiiliaga (nt Kossinets & Watts, 2009), kus keel ja kultuur on olulised siduvad tunnused suhete moodustamisel. See tulemus on seostatav ka etnilise segregatsiooniga erinevates igapäevastes tegevuskohtades (Kukk et al, 2019; Masso & Soll, 2014; Mägi et al, 2016,) ning tegevusruumis tervikuna (nt Järv et al, 2015; Silm et al, 2018). Venekeelsetele inimestele tähendavad samarahvuselised võrgustikud ja elamine ning liikumine sama keeleruumiga piirkondades kulgemist n-ö segregatsiooni nõiaringis (Krysan & Crowder, 2017; van Ham et al, 2018). Eestikeelsete samarahvuseliste võrgustike osakaal peegeldab suuremat liikmete valikut potentsiaalsetes võrgustikes, kuid võib viidata ka kõrgemale sotsiaalmajanduslikule staatusele, mis viib eraldamiseni vähemustest ja madalama sotsiaalse staatusega inimestest (nt Priest et al, 2014; Yip et al, 2016). Kuna mitmerahvuseliste

võrgustikega eestikeelsed inimesed liiguvad vähem kui samarahvuselise võrgustikuga eestikeelsed, võib tulemust osaliselt selgitada ka etnilise ja sotsiaal-majandusliku segregatsiooni kattumine (Järv et al, 2021). Eestikeelsetele võib sage kokkupuude venekeelsetega elukoha piirkonnas seostuda ühtlasi ka eelarvamuste vabama olustiku ja suurema venekeelsete usaldamisega, mis suurendab kontakti sotsiaalsete rühmade vahel (Grossetti, 2005; Heizmann & Böhnke, 2016).

Üle-eestiline mobiilikasutajate uuring sedastas erinevusi asustushierarhias. Tihedamalt asustatud piirkondades olid seosed võrgustiku ruumilise ulatuse ja ulatuslikuma ruumikasutuse vahel tugevamad, näiteks Tallinnas või piirkondlikes keskustes. Seosed on nõrgemad hõredamalt asustatud piirkondade elanikel (nt väikelinnad ja maapiirkonnad). Seega on suurema asustustihedusega piirkondades võrgustikud ja tegevuskohad ruumiliselt kontsentreeritud, mida on kinnitanud näiteks ka Phithakkitnukoon *et al* (2012) poolt läbi viidud uuring. Neid erinevusi on võimalik selgitada ka erinevate piirkondade võimalustega, nagu ligipääsetavus erinevatele teenustele (Meurs & Haaijer, 2001; Scheiner & Kasper, 2003). Samuti mõjutas elu- ja töökoha kaugus võrgustiku paiknemise ja ruumilise mobiilsuse seost: seosed olid nõrgemad elukohast kaugemal töötamisel. Tulemused selgitavad koondunud võrgustike ja suure ruumilise mobiilsusega tüübi puudumist töö tüpoloogias, kus inimesed elavad ja töötavad samas linnas.

Doktoritöö esitab tüpoloogia, mis autori teada on esimene samaaegselt isiklike võrgustike paiknemist ja ruumilist mobiilsust hõlmav lähenemine siseriiklikult. Inimgeograafiale on töö oluline, sest loob tugevama seose isiklike võrgustikega, mille edasisele uurimisele annab aluse ka töös esitatud teoreetiline raamistik. Töö aitab ka senisest paremini mõista etnilist segregatsiooni Eestis, sidudes senised teadmised rahvusrühmade erinevast ruumilisest käitumisest isiklike sotsiaalsete võrgustike paiknemise ja etnilis-keelelise koosseisuga. Kõik doktoritöö aluseks olevat uuringut kinnitavad isiklike sotsiaalsete võrgustike ja ruumilise mobiilsuse vahelisi olulisi seoseid. Erinevalt traditsioonilistest lähenemisest tugineti geograafilistele mõõtmetele ja pikematele ajaperioodidele, mis võimaldavad saada ulatuslikuma pildi nii võrgustikest kui ka ruumilisest paiknemisest. Teiste mobiilipõhiste uuringutega võrreldes kaasasid uuringud erinevaid isikute, IKT kasutuse, võrgustiku koosseisu ja igapäevaste tegevuskohtadega seotud tunnuseid. Töö olulisus seisneb üldistest seaduspäradest ja trendidest kaugemale vaatamises.

Doktoritöö tulemused viitavad vajadusele võrgustike paremaks mõistmiseks, et selgitada ühiskondlike nähtuste ja ebavõrdsuse põhjuseid. Etniline segregatsioon, soolised erinevused ja juurdepääsetavus on vaid mõned näited, mida saab isiklike mobiilisuhtlusel tuginevate võrgustikke analüüsides uurida. Teoreetiliselt on homofiilia kui kalduvus luua suhteid endasarnastega oluline lähtepunkt, mis aitab ühiskonna erinevate rühmade eelarvamusi ja hoiakuid mõista. Samuti on see oluline erinevate rühmade ruumilise sorteerituse mõistmiseks, mis võivad tugineda näiteks sotsiaalmajanduslikul staatusel, etnilisusel ja väärtushinnangutel. Töös tulemused kaardistavad olukorda enne COVID-19 seotud kriise ja piiranguid. Kuna nii isiklikud sotsiaalsed võrgustikud kui ka ruumiline mobiilsus on viiruste leviku keskmeks, võib lähiaastatel oodata veelgi uuringuid, mis neid aspekte käsitlevad (nt Block et al, 2020; Scala et al, 2020). Seoste mõistmine on

vajalik nii kriiside ohjamiseks, kuid ka selleks, et mõista uute poliitiliste piirangute mõju erinevatele ühiskondlikele rühmadele, kelle sotsiaalne elu ja senine rutiin on neist mõjutatud ja mis eeldab üksikisiku vaatest olulisi igapäevaelu muudatusi. Lähenemine võrgustike teooriatele ja meetoditele on vajalik, pakkudes ühise keele ja seeläbi võimalused ka valdkondade ülesteks uuringuteks.

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PUBLICATIONS

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Publications:

Puura, A., Silm, S., Masso, A. (2022). Identifying relationships between personal social networks and spatial mobility: A study using smartphone tracing and related survey. *Social Networks*, 68, 306–317. DOI: 10.1016/j.socnet.2021.08.008.

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Conference presentations:

Puura, A., Silm, S., Masso, A. (June 2018). *Differences in ICT use and its relationships with personal social networks and spatial mobility.* Oral presentation at the Mobile Tartu 2018. Tartu, Estonia.

Puura, A. (April 2018). *Activity-travel behaviour and coupling constraints – study by using smartphone tracking data and related interviews*. Oral presentation at the Association of American Geographers (AAG) Annual Meeting. New Orleans, US.

Puura, A. (September 2017). *Smartphone tracking and social network studies*. Oral presentation at the Workshop on Data Processing and Analytics of Smartphone and GPS Data. Tartu, Estonia.

Puura, A. (May-June 2017). *Locations of social networks as part of daily activity space*. Oral presentation at the XXXVII Sunbelt Social Networks Conferences of the International Networks for Social Network Analysis (INSNA). Beijng, China.

Puura, A., Silm, S., Ahas, R. (June-July 2016). *Patterns of co-presence in geographically distant relationships*. Oral presentation at the Mobile Tartu 2016. Tartu, Estonia.

Puura, A., Silm, S., Ahas, R. (June 2015). *Relationships between social networks and individuals' use of space: a study using mobile phone-based data*. Oral presentation at the 6th Nordic Geographers Meeting (NGM). Tallinn/Tartu, Estonia.

Puura, A., Ahas, R., Silm S. (March 2014). *The effect of social networks on people's spatial mobility*. Oral presentation at the Association of American Geographers (AAG) Annual Meeting. Tampa, US.

Other scientific activities:

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Oral presentations at the meetings:

Puura, A., Ahas, R. (June 2015). *The study of social networks and travel behaviour with mobile phone-based data*. 3MC and 2 WG meetings. Budapest, Hungary.

Puura, A., Silm, S., Ahas, R. (May 2016). *Patterns of co-presence in geographically distant relationships*. 5MC and WGs meetings. Bucharest, Romania.

Courses:

2014–2017	"Research Methods in Human Geography" (LOOM.02.258)
2015–...	"Geography, Communication and Spatial Mobility" (Eng) (LOOM.02.073/LTOM.02.050)

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Haridus:

2014–2022	Tartu Ülikool, PhD inimgeograafia erialal
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Publikatsioonid:

Puura, A., Silm, S., Masso, A. (2022). Identifying relationships between personal social networks and spatial mobility: A study using smartphone tracing and related survey. *Social Networks*, 68, 306–317. DOI: 10.1016/j.socnet.2021.08.008.

Silm, S., Mooses, V., Puura, A., Masso, A., Tominga, A., Saluveer, E. (2021). The relationship between ethno-linguistic composition of social networks and activity space: A study using mobile phone data. *Social Inclusion*, 9 (2), 192–207. DOI: 10.17645/si.v9i2.3839.

Puura, A., Silm, S., Ahas, R. (2019). The relationship between social networks and spatial mobility. A mobile phone-based study in Estonia. In: Plaut, Pnina O; Shach-Pinsly, Dalit (Ed.). *Digital Social Networks and Travel Behaviour in Urban Environments* (pp. 72–93). London: Routledge. DOI: 10.4324/9780429488719-6.

Puura, A., Silm, S., Ahas, R. (2018). The relationship between social networks and spatial mobility: A mobile phone-based study in Estonia. *Journal of Urban Technology*, 25 (2), 7–25. DOI: 10.1080/10630732.2017.1406253.

Suulised ettekanded konverentsidel:

Puura, A., Silm, S., Masso, A. (juuni 2018). *Differences in ICT use and its relationships with personal social networks and spatial mobility.* Mobile Tartu 2018. Tartu, Eesti.

Puura, A. (aprill 2018). *Activity-travel behaviour and coupling constraints – study by using smartphone tracking data and related interviews.* Association

of American Geographers (AAG) Annual Meeting. New Orleans, Ameerika Ühendriigid.

Puura, A. (september 2017). *Smartphone tracking and social network studies*. Workshop on Data Processing and Analytics of Smartphone and GPS Data. Tartu, Eesti.

Puura, A. (mai-juuni 2017). *Locations of social networks as part of daily activity space*. XXXVII Sunbelt Social Networks Conferences of the International Networks for Social Network Analysis (INSNA). Peking, Hiina.

Puura, A., Silm, S., Ahas, R. (juuni-juuli 2016). *Patterns of co-presence in geographically distant relationships*. Mobile Tartu 2016. Tartu, Eesti.

Puura, A., Silm, S., Ahas, R. (juuni 2015). *Relationships between social networks and individuals' use of space: a study using mobile phone based data*. Oral presentation at the 6th Nordic Geographers Meeting (NGM). Tallinn/Tartu, Eesti.

Puura, A., Ahas, R., Silm S. (märts 2014). *The effect of social networks on people's spatial mobility*. Oral presentation at the Association of American Geographers (AAG) Annual Meeting. Tampa, Ameerika Ühendriigid.

Muu teadustegevus:

2014–… Rahvusvahelise konverentsi Mobile Tartu korraldustoimkonna liige

COST projekt TU1305 Social Networks and Travel Behaviour. Osalemine noorteadlasena.

Suulised ettekanded kohtumistel:

Puura, A., Ahas, R. (juuni 2015). *The study of social networks and travel behaviour with mobile phone-based data*. 3MC and 2 WG meetings. Budapest, Ungari.

Puura, A., Silm, S., Ahas, R. (mai 2016). *Patterns of co-presence in geographically distant relationships*. 5MC and WGs meetings. Bukarest, Rumeenia.

Kursused:

2014–2017	"Inimgeograafia uurimismeetodid" (LOOM.02.258)
2015–...	"Geograafia, kommunikatsioon ja ruumiline mobiilsus" (LOOM.02.073/LTOM.02.050)

DISSERTATIONES GEOGRAPHICAE UNIVERSITATIS TARTUENSIS

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3. **Ülo Suursaar.** Soome lahe avaosa ja Eesti rannikumere vee kvaliteedi analüüs. Tartu, 1993.
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