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Influence of Social Relationships on Decisions in Device-to-Device Communication

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ABSTRACT Device-to-device (D2D) communication is an innovative solution for improving wireless network performance to efficiently handle the ever-increasing mobile data traffic. Communication takes place directly between two devices that are in each other's transmission range. So far, research has focused on the technical challenges of implementing this technology and assumes a user's general willingness to participate as forwarder in this technology. However, this simplifying assumption is not realistic, as willingness to participate in D2D communication can vary depending on the user. In this work, we consider the scenario that a user can act as a forwarder for a receiver who is not directly or insufficiently reached by the base station and accordingly has no or poor Internet connection. We take a user-centric approach and investigate the willingness to provide an Internet connection as a forwarder. We are the first to investigate user preferences for D2D communication using a choice-based conjoint analysis. Our results, based on a representative sample of potential users ($N = 181$), show that the social relationship between the potential forwarder and the receiver has the greatest impact on the potential forwarder's decision to provide an Internet connection to the receiver, accepting sacrifices in terms of additional battery consumption and reduced own service performance. In a detailed segment analysis, we observe significant preference differences depending on smartphone usage behavior and user age. Taking the corresponding preferences into account when matching forwarders and receivers can further increase technology adoption.

INDEX TERMS Conjoint analysis, consumer behavior, device-to-device communication, mobile communication, user preferences, user study, willingness to forward, wireless communication, wireless networks.

I. INTRODUCTION

For more than a decade, we see a revolution in mobile connectivity by introducing a plethora of Internet-based applications. The rise of mobile electronic devices seems inexorable and is not only represented by a globally increasing demand for laptops, tablets, or smartphones. Innovations keep flooding the market with new products that all require a connection to the Internet. As research by Cisco [1] suggests, the global mobile data traffic is indeed set to multiply over the next couple of years.

Two major trends mainly drive this unambiguous development: a steady increase in active network participants and an observable change in usage behavior regarding mobile data, such as the rising demand for resource-consuming mobile video traffic. Both inevitably result in congested networks at some time, and thus a bad customer experience, challenging existing network structures (see, for example, [2]).

As a result, network operators face the challenge of offering suitable solutions that efficiently handle an overwhelming demand for mobile data traffic and reducing potential bottlenecks in the network to satisfy customer experience.

Whereas expanding the network capacity by investing in network infrastructure, such as additional base stations, may be a viable and obvious solution, this progression would probably neither hold pace with the rapid developments in demand for mobile data nor would it necessarily be compatible with a cost-efficient business model. Hence, new and innovative solutions must be sought to organize and schedule future mobile data traffic and revolutionize existing approaches.

Wireless networks are more important than ever in this context. The fifth generation (5G) in particular promises many performance benefits such as higher data rates, lower end-to-end latency, and lower energy consumption of the

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devices. In addition to the traditional mode of operation, which involves the transmission from base stations to end devices, 5G also offers the possibility of device-to-device (D2D) communication, as additional base stations alone are not a suitable solution. D2D communication is a key technology provided to enhance the performance of 5G and enable traffic offloading to smaller and more flexible network structures, which reduces congestion by establishing connections between devices [3]. As this alternative solely requires a direct connection between devices in the transmission range of each other, the network's performance is no longer dependent on the fixed infrastructure of base stations or routers. By enabling D2D communication on different devices, the performance of the overall system can be optimized.

In mobile wireless networks, the available devices usually belong to the respective users, whose mobility and usage behavior influence the possible network structure. Accordingly, the technology can only be successful if many users who are in the vicinity participate cooperatively and act as forwarders. Therefore, it is important to understand under what conditions users are willing to participate in D2D communication. In addition, it is crucial to study the social behavior of users in terms of where and in what environment users spend longer periods of time, as they can participate in D2D communication during the appropriate periods in the nearby environment.

However, previous research has mainly focused on the technical challenges that arise from the implementation of D2D communication (e.g., [4], [5]). Moreover, the scientific focus is particularly on peer discovery [6], resource allocation [7], interference management [8], security and privacy [9], or energy efficiency [10], mainly ignoring the perspective of potential users. Although there are occasional studies in the area of socially-aware D2D communication and social interactions between D2D users (e.g., [11]), they focus on classifying the technical problems of socially-aware D2D communication, so that a research approach from a user-centered perspective is still lacking.

To extend existing research, we present a user-centered approach in the context of D2D communication. To the best of our knowledge, we are the first to conduct a user study in this area to gain insights into user preferences and willingness to participate. Thus, we explore what factors influence users' willingness to participate in D2D communication and how these factors influence users' decisions. Our results provide insights into how appropriate technologies should be designed in order to encounter broad acceptance and be successful accordingly.

For our user study, we develop a concrete scenario of such a D2D communication, considering both the technical impact on the devices and the social network. In this scenario, we assume that the survey participants are connected to the base station and thus have a good Internet connection. Further, there is one person, the receiver, with poor or no Internet connection. The survey participants can now decide

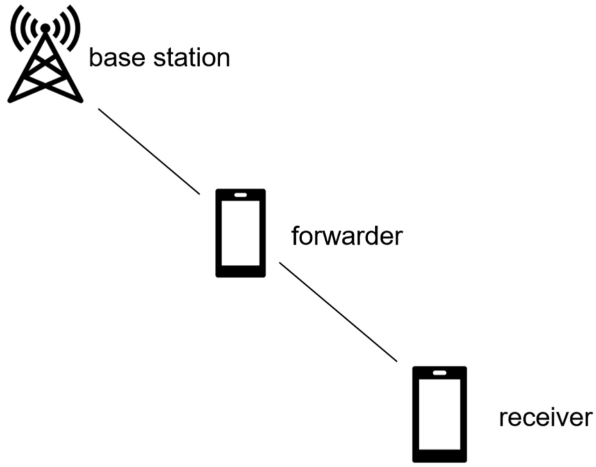

FIGURE 1. D2D forwarding scenario.

to act as forwarders and provide an Internet connection to the receiver or not. Fig. 1 shows the provisioning of the Internet connection between forwarder and receiver. Possible factors that may influence this decision in our scenario are the current situation of the receiver, the relationship between the potential forwarder and the receiver, the additional battery consumption for the forwarder, and the remaining service performance of the forwarder.

In our article, we focus on the intrinsic altruistic motivation of potential users and accordingly do not set any additional incentives. Thus, the central question of this paper focuses on the importance of social relationships among potential users and how these may influence the decision to act as forwarders for others.

To directly assess potential users' opinions and preferences, we conduct an online survey with 181 respondents. The three-parted online survey aims to obtain insights into respondents' general social behavior, personality, and preferences for providing Internet connection to others based on different social relationships. As an analytical tool for measuring the preferences regarding specific configurations in D2D communication, we apply a choice-based-conjoint analysis.

The remainder of this paper is organized as follows: In the next section, we derive the theoretical framework for social-aware mobile networks by giving a brief literature review and formulating three hypotheses regarding technology adoption and potential motives to participate in D2D communication. Subsequently, we outline the choice of methodology and the setup of our empirical study. Section IV comprises the analysis and discussion of our results. Finally, in Section V, we present the conclusions and ideas for future research.

II. RELATED RESEARCH

In the following, we first provide an insight into the theoretical foundations and relevant research projects of D2D communication, its advantages, and disadvantages. Furthermore, we consider the influence of social relationships and their integration into the network structure as well as aspects that may hinder or motivate participation in D2D communication.

A. MOBILE NETWORKS

1) D2D COMMUNICATION

The term device-to-device (D2D) technology refers to communication networks formed by their users. Instead of relying on fixed network infrastructures, devices that are in close proximity can build the network in an ad hoc manner by establishing direct connections among each other [12]. This achieves multiple performance parameter improvements such as higher throughput, lower latency, and better energy efficiency [2].

All nodes within such networks are represented by the users' devices and organize themselves dynamically and freely, creating the network topology that best meets current requirements. Devices within the transmission range of each other can establish a direct connection - based on single-hop connections. A larger number of devices can be integrated by allowing multi-hop approaches. In this case, messages are successively forwarded to their final destination through a series of devices, enabling communication between devices that are not in close proximity [5]. However, in this article, we restrict to two-hop connections between a base station, a forwarder, and a receiver, where the latter two must cooperate to spin up a network, as shown in Fig. 1.

2) BENEFITS AND CHALLENGES

From a network operator's perspective, Quality of Service (QoS) and Quality of Experience (QoE) are important indicators for network service quality. QoS is usually measured in metrics such as data rate or packet loss. The technical network performance parameters for mobile and wireless systems are determined by traffic volume density, experienced end-user throughput, latency, reliability, availability and retainability, energy consumption, and costs [13]. However, previous research shows that increasing QoS does not necessarily lead to more satisfied users [14]. The decisive factor here is the interaction with QoE, which considers the subjective perception of an end-user and the associated general acceptance of a service [15]. QoE can be used to measure user satisfaction, which is closely related to user preferences. User satisfaction can be increased if technologies or products are aligned with user preferences. Accordingly, accurate knowledge about user preferences and their consideration when implementing technologies is extremely important for success. Thus, in our study, we focus on user preferences with regard to D2D communication.

Previous research has rather investigated the influence of network structures on the above-mentioned technical network performance parameters when implementing D2D communication (see, for example, [16], [17]). Vanganaru *et al.* [18], who mainly refer to coverage-related factors such as availability, show how users on the periphery of today's cellular networks can benefit from D2D connections. On the one hand, these users can access more data services and thus experience better network quality. On the other hand, D2D communication offers savings for the network operator, who would otherwise have to make additional, potentially inefficient investments in its infrastructure to reach and serve users at the edge of the network. Furthermore, offloading parts of the mobile data traffic to the connections between the respective users reduce the risk of network congestion and thus increases the reliability of the network service performance.

Whereas previous research already shows possible improvements in overall network performance, each individual must participate in such D2D communication to reach its full potential. Accordingly, many studies assume a general cooperative behavior of all individuals and disregard subjective interests at the user level (e.g., [2]). However, individuals typically pursue their own interests and can therefore show selfish behavior, e.g., when providing (or not) Internet connection [19]. This factor could be further intensified within mobile networks due to the permanent uncertainty about the available network quality and the battery state of the users' devices. In this way, the limited battery may cause users to be reluctant to collaborate [20].

However, a minimum level of trust is required to establish D2D connections [11]. Nevertheless, user participation is essential for the implementation of D2D communication. Accordingly, it is important to consider implementing such connections from the user perspective to understand and analyze the impact of user preferences on the network performance. Only if the technology aligns with user preferences it will be accepted by the users and thus become a success.

The main stages of the routing process of D2D communication are route and device selection, route maintenance, and final distribution of data packets. This process requires continuous communication as well as storage and processing effort on the part of the individual devices and therefore impacts the battery, computing power (CPU), and memory capacity (RAM) of the devices, with which each device is equipped only to a limited extent [21], [22]. The additional battery consumption has the most apparent effect on the users. Since battery level preferences are usually very subjective, generalized assumptions cannot be made about the entire set of users. Thus, not only the limited resources of the individual devices cause some users to exhibit selfish behavior and exclude themselves from the network [19] but also their different preferences.

Especially devices located in the center of D2D scenario may suffer from more requests and thus a heavier load since they are elementary for a stable network structure and are therefore selected more frequently. To address this problem, Liang and Ren [23] suggest a routing protocol that considers situational factors such as the current battery status of a device. Although this approach provides a good starting point, upcoming research should consider further factors and the corresponding user preferences. D2D communication relies on mobility and thus on the social interactions that users face in their daily lives since forwarders and receivers need to be in close proximity for a certain amount of time for the meaningful establishment of D2D communication and corresponding data transmission. We discuss these social structures and their possible integration into the existing network in the following section.

B. SOCIAL-AWARE MOBILE NETWORKS

1) SOCIAL INTEGRATION

In recent years, progress in the field of social-aware mobile networks was primarily achieved in real-world projects that were able to trace human mobility behavior and thereby obtain specific connectivity patterns. These traces and the subsequent network design enable a detailed understanding of how the connections can be used for D2D communication and how data are routed through the network. They also pave the way for developing specific routing protocols and routing schemes that use the social network.

In several studies with different experimental settings, selected users were equipped with special devices and told to proceed with their daily life as usual (e.g., [24], [25]). After a predefined data collection period, the users had to return the devices. Based on logs made through Bluetooth connections between all devices, the social network structure, including frequency and duration of connections, could be derived. Although the studies approach the subject in a purely technical manner, they provide insight into existing network structures that can be used to establish D2D communication better.

Regarding the willingness to cooperate within these networks, we observe two literature streams (see [26] for a comprehensive review): one line of research assumes a general willingness of each user to participate and focuses on the integration and use of social connections in specific routing and forwarding mechanisms. Another stream considers that individuals may behave in their own interest and model all users' behavior under selfish behavior [27]. However, for effective network design, users' altruistic and selfish behavior should be considered together since users may exhibit altruistic or selfish behavior depending on their counterparts [11].

Therefore, in our work, we assume neither a completely cooperative nor a purely selfish behavior. Instead, we examine the extent to which social network structures can be used to induce cooperative behavior. In contrast to most previous works, we do not introduce incentive mechanisms to increase cooperativeness based on, for example, credit, self-interest, reputation, service, bandwidth exchange, or monetary incentives and others [5], [11], [28]. Instead, we analyze the purely altruistic motivation of participants. We thus take a user-centric approach that provides insights into actual preferences and willingness to participate in such networks. This perspective is important because technologies must be tailored to users and their preferences if these technologies depend strongly on users' willingness to participate. Our user study will help in the future development of D2D communication that leverages users' preferences for potential participation as forwarders, taking into account social relationships.

2) PARTICIPATION MOTIVES

Whereas the advantages of D2D connections are visible in the technical domain by equally distributing traffic across all devices and at the same time minimizing the number of devices directly connected to a base station, this does not reflect the concerns of most users. Therefore, based on existing research and the considerations in this paper, we seek to understand better the underlying motivational mechanisms for participating in D2D communication as forwarders and thus provide Internet connection to other users.

Whereas the receiving side has the advantage of accessing mobile data services, the motivation for the forwarder may be less obvious. The forwarders experience reduced service performance as well as higher battery consumption. A rational user, limited to considering only technical aspects, would thus decide against providing an Internet connection to others since the forwarder experiences only disadvantages if no additional external benefits or incentives are offered simultaneously. Previous studies, therefore, focus on schemes to enforce cooperation between users. In this context, Yoo and Agrawal [19] divide these approaches into three groups: reputation-based schemes, credit-payment schemes, and game-theoretic schemes, but all of them have apparent drawbacks in their implementation.

However, many social science studies show that humans do not always behave rationally. Instead, personality-related factors play a significant role in explaining this supposedly "irrational" behavior [29], which in our context presents itself as voluntary cooperation without any additional incentive mechanism. This is particularly important in social settings in which one person is asked to help another. Studies from behavioral economics seek a clear understanding from an economic perspective of how individuals execute decisions in an economy-related setting, such as purchase decisions or information exchange settings. However, it is unclear what motives lead the forwarder to help another person when no additional benefit becomes apparent.

One argumentation can be found in social behavior theories and, more specifically, in the so-called *Hamilton Rule* [30]. It justifies social or even altruistic behavior based on the simplified theorem $Cost < Benefit * Relationship\ Value$. In other words, the costs of conducting a specific action have to be smaller than the product of the perceived benefit and the relationship value between the two counterparts. Based on this, a stronger relationship between the counterparts should lead to an increased willingness to help and thus to act as a forwarder in D2D communication without the need for incentives. Previous research in the context of mobile social networks already assumes that users' social awareness could improve the efficiency of the networks [31] or that users could exhibit altruistic behavior or selfish behavior depending on the counterpart [11]. To date, however, these assumptions have not been further investigated or substantiated from the user perspective.

C. HYPOTHESES DEVELOPMENT

In the following, we formulate hypotheses for the structured and strategic examination of our research topic. The hypotheses help us realize our research in a goal-oriented way by first establishing scientific propositions for our research field based on previous findings, then creating and adapting our study design, and finally analyzing these propositions through the study results.

In addition to the aforementioned Hamilton Rule, Glaeser *et al.* [32] show that trust (and trustworthiness) increase with an existing (friendship) relationship. Wijngaert and Bouwman [33] studied this factor for sharing behavior in the context of wireless grids. They argue for the importance of a strong relationship between the parties. In particular, they stated that people might feel more reluctant to provide resources to strangers or acquaintances due to security and privacy reasons [33]. Likewise, Ahmed *et al.* [11] assume that trust between the participating communication entities is a prerequisite for successfully realizing mobile social networks. Within the specific context of D2D communication, most people might feel insecure about how participation in such D2D communication may affect the privacy of their data - a topic widely discussed in media reports and studies (see, for example, [34], [35]). Therefore, people may be more willing to act as a forwarder for their family and friends with whom a trust relationship already exists than for casual contacts or strangers with whom the necessary level of trust is lacking. Thus, we propose the following hypothesis:

> ***H1 (Social Relationship):*** *Individuals are more willing to act as forwarders for people with whom they share a closer social relationship, and a trust relationship already exists.*

Another part of the Hamilton Rule concerns the perceived benefit of the helping person, i.e., the forwarder. Relevant studies suggest that factors such as reputation among peers may influence these decisions and that motivation may lie in each person's personality [36]. In our scenario, we consider only two users, the receiver and the forwarder. So the forwarder's decision whether to provide an Internet connection or not is not visible to others. Possible influencing factors such as competition or status should play a minor role in deciding to act as forwarders. Therefore, we assume that the corresponding motives are purely intrinsic. This brings the factor *altruism*, i.e., the selfless behavior of helping another person without expecting additional (external) rewards, into the foreground [37]. Altruism is a commonly studied character trait that can impact an individual's interaction with others [38]. Considering the definition stated above, we can argue that people who behave strongly altruistically would act as forwarders even if they face restrictions on their own and do not receive any compensation. Therefore, our second hypothesis is as follows:

> ***H2 (Altruism):*** *Individuals who show altruistic characteristics are more willing to act as forwarders for others.*

Summing up, we identified the factors *Social Relationship* and *Altruism* as the main drivers that influence the decision to provide an Internet connection from an individual's perspective. Considering those alongside subjective situational costs, the forwarding user has to balance different criteria to decide for acting as a forwarder for others.

Finally, we shift the view to a more general approach in technology adoption to identify decisive factors for the acceptance and widespread adoption of our examined technology. Broad user adoption is of great importance, as this is a key factor in the success of the technology. In this context, it is essential to differentiate between pre-and post-adoption criteria. Whereas many studies research the factors that made a specific technology successful in the retrospective, these results have only limited validity when applying the findings to newer technologies that provide service offerings that differ strongly from established technologies [39].

A theoretical model that aims to explain why individuals do or do not adopt certain technologies was firstly introduced by Davis *et al.* [40]. Their research about user acceptance of computer technology serves as a foundation for the study conducted in this paper. The proposed framework was presented as the 'Technology Acceptance Model (TAM)', according to which two central elements are the major drivers for technology adoption: perceived usefulness of technology and its perceived ease of use.

The former aims to describe the positive impact the usage of a particular technology has on the user, and the latter refers to the expectation of how easy a new technology can be used. More recent studies aim to transfer the TAM to the specific case of mobile data services and their acceptance amongst potential users. Ovčjak *et al.* [41] provide an extensive study of additional factors potentially impacting the acceptance of mobile data services.

In addition, as already mentioned, personality-related variables are of importance. In this context, Fogel and Nehmad [35] investigated the influence of social relationships and personal innovativeness on adopting wireless Internet services via mobile technology. Eckel and Grossman [38], who extended the existing TAM model to include the element of personal innovativeness. Thereby, individuals who adapted innovations earlier than the majority of people are classified as 'innovative'. Personal innovativeness also influences an individual's intrinsic motivation, reinforcing the perceived usefulness of a technology. Whereas Fogel and Nehmad [35] found no direct effect of personal innovativeness on the adoption of wireless Internet services, they observed a mediating effect: The authors attested a strong positive influence on perceived usefulness and perceived ease of use, which ultimately leads to technology adoption. Based on the existing studies in this area and the reasoning presented above, we hypothesize that technology anxiety (affinity) negatively (positively) influences participation in D2D communication by providing

Internet connections to others. Therefore, we formulate the third and final hypothesis as follows:

H3 (Technology Anxiety): *Individuals who are uncomfortable with using technology and show anxiety for using technology are less likely to act as forwarders for others.*

III. METHODOLOGY

In the following, we explain our methodological approach. We conduct an online survey to obtain structured responses from participants to investigate the influence of social relationships on the decision to act as forwarders and thus provide Internet connection in the context of D2D communication. For this purpose, we conduct a choice-based-conjoint analysis (CBC) to measure the underlying user preferences.

A. RESEARCH METHODOLOGY

Most studies in the field of social-aware D2D communication emphasize technical implementation and do not incorporate user preferences into the concept. Therefore, it is important to obtain representative results based on a large data sample: Instead of focusing on a specific design of the new technology, we shift the focus to a general understanding of the mechanisms and essential elements within D2D communication. CBC is a state-of-the-art method for eliciting preferences. It is widely used and established in behavioral science and market research [42]. In a CBC study, respondents are repeatedly asked to make hypothetical choice decisions among a set of product or technology alternatives described by their attributes and corresponding attribute levels. In doing so, respondents make trade-off decisions between the attractiveness of the alternatives from which we gain valuable insights into user preferences - even if the underlying technology does not yet exist [43].

Additionally, we present a no-choice option in each choice set, which participants can select if none of the technology alternatives provide sufficient benefits to justify participation. This experimental design is more realistic than traditional conjoint analyses due to the similarity of these choices to real-world decisions, so that CBCs explain actual adoption behavior well. CBCs with no-choice options are therefore a popular and frequently used survey method [44], [45]. One drawback is that when respondents select the no-choice option, we do not reveal any information about the trade-off between the attractiveness of the attribute levels in the product alternatives. If participants choose the no-choice option frequently, the technology presented may not be attractive enough or may be too expensive.

B. STUDY SETUP

In our study with real users, we want to determine how high the altruistic willingness is to act as a forwarder and provide an Internet connection to others, as shown in Fig. 1. We also investigate how strongly the factors *current situation of receiver, relationship to receiver, additional battery consumption* of forwarder, and *remaining service performance* of the forwarder influence the decision to act as a forwarder. Regarding the selection of attributes and the corresponding attribute levels, as well as the structure of our study, we avoid abstract technical terms in the description of our D2D communication scenario and approach the topic from a user-centric perspective to increase the comprehensibility of the presented technology. Consequently, we simplify the technical dependencies and reduce them to generally applicable mechanisms. With this approach, we follow the methodology of [45] by simplifying the scenario to represent valid considerations of the impact on the network and users' devices but allow for a clear evaluation by all survey participants.

We embed our CBC in a clearly defined scenario so that participants can concretely envision their selection decision. In particular, our presented technology allows survey participants to act as forwarders and thus provide Internet connection via their own smartphone to other people in the environment with severely limited or no Internet connection, called receiver. The participant knows the social relationship with the potential receiver.

It is also essential for participants to know that there are costs associated with providing an Internet connection. On the one hand, the service performance of the forwarder is restricted during the provisioning of the Internet connection; on the other hand, forwarding leads to increased battery consumption.

Thus, for our CBC, we chose the four attributes *current situation of receiver, relationship to receiver, additional battery consumption* of forwarder, and *remaining service performance* of the forwarder that we believe significantly impact users' forwarding readiness. According to hypothesis 2, we want to analyze the purely altruistic motivation of the participants and, therefore, we do not impose any additional extrinsic incentives. We assign attribute levels to each attribute and then create different technology alternatives in the choice sets. Through the choices in the different choice sets, we can thus analyze the participants' preferences for the individual attributes and the associated attribute levels and understand under which conditions the participants are willing to act as forwarders.

In the following, we explain the selection of attributes and attribute levels that define the possible service configurations in our study and potentially influence the decision of study participants to act as possible forwarders and thus provide an Internet connection.

1) ATTRIBUTE 1–CURRENT SITUATION OF RECEIVER

Several studies show that donors tend to spend more when knowing about the receiving side's helpless situation [38]. Accordingly, we assume that the forwarding side might evaluate its decision differently when the receiving side is in a needier situation, thus increasing the effect of helping. Correspondingly, we include the attribute *current situation of*

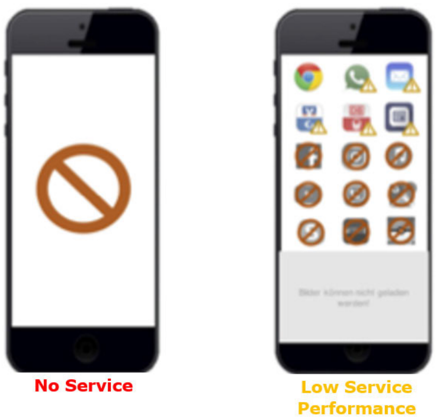

FIGURE 2. Current situation of receiver.

receiver as contextual information about the receiver in our study.

We select two attribute levels for this attribute: *no service* and *low service performance*. The receiver thus either has no Internet connection at all and accordingly cannot use any mobile data service, or this access is severely restricted to the most essential functions. In the latter case of *low service performance*, the receiver experiences limited use with some apps and can, for example, only exchange purely text-based messages via messenger services and use helpful navigation or banking apps only to a limited extent because the graphical content usually cannot be loaded. However, access to the most important information is guaranteed. Some apps are not available because loading fails due to timeouts. Thus, all apps used for entertainment purposes are unusable on this attribute level.

Fig. 2 contains a graphical representation for the attribute levels. In the case of low service performance, the associated restrictions of the apps are clearly visible. For better understanding, this visualization was also presented to the participants during the study.

2) ATTRIBUTE 2–RELATIONSHIP TO RECEIVER

Following hypothesis 1 and the social relationship concepts anchored there, we include the attribute *relationship to receiver* in our study. Previous research shows that individuals act more altruistically towards members of their community and those they know or have a close relationship with [11], [46]–[48]. To not put the forwarder in a situation of social pressure, only the forwarder knows about this relationship with the potential receiver and is thus free to decide whether or not to allow this person to connect. The receiver does not know about the possible forwarders in the vicinity and their social relations with him/her. Within this attribute, we define four levels: *family/partner, friend, acquaintance*, and *stranger*. Following Pelusi *et al.* [49], we define these groups in more detail in Table 1.

We assume that the social relationship with a stranger is the weakest and becomes stronger up to the highest level family/partner.

TABLE 1. Grouping and definition of social contacts.

Group	Definition
Family & Partner	People you count as part of your close family or with whom you have a solid partnership
Friends	People with whom you have a good personal relationship and maintain long-term contact
Community Members/ Acquaintances	People with whom you share work, sports, or other common interests or hobbies
Strangers	People whom you do not know and do not share any commonalities

3) ATTRIBUTE 3–ADDITIONAL BATTERY CONSUMPTION

The forwarder incurs costs in the form of higher battery consumption by providing an Internet connection to the receiver. Accordingly, we include the *additional battery consumption* of the forwarder as another attribute in our study. Previous research shows that battery consumption is a major worry and thus an important concern for users in terms of Internet provisioning [11], [47], [48], [50]. In their two experiments in the context of opportunistic networks, Bermejo *et al.* [48] show that users generally exhibit strong altruistic behavior, although this drops off sharply when the battery level drops tremendously.

In our study, this battery consumption is in addition to the smartphone's regular consumption during the time of the Internet connection. To investigate the impact of this cost on the respondents' trade-off decision, we vary between three potential attribute levels: *5%*, *10%*, and *15% additional battery consumption* during forwarding. These values are realistic for our scenario in which respondents provide their Internet connection for a period of 20 minutes. Depending on how energy-efficient the forwarding technology is developed and to what extent the receiver accesses its Internet services during forwarding, we assume a minimum of 5% and a maximum of 15% additional battery consumption. For respondents for whom battery consumption is of high importance, the amount of additional battery consumption may play a decisive role in the decision to provide an Internet connection to others.

4) ATTRIBUTE 4–REMAINING SERVICE PERFORMANCE

Participation in D2D communication entails further costs for the forwarder, as this technology uses a fraction of the forwarder's bandwidth from its connection to the base station for the data stream forwarded to the receiver. As a result, the forwarder's own service performance deteriorates.

In addition, computationally and memory-intensive processes reduce the perceived service performance of the forwarder, who naturally also wants to use its own services during forwarding. Since the reliable execution of too many parallel tasks cannot be guaranteed, we expect the service performance of the forwarder to be downgraded when providing

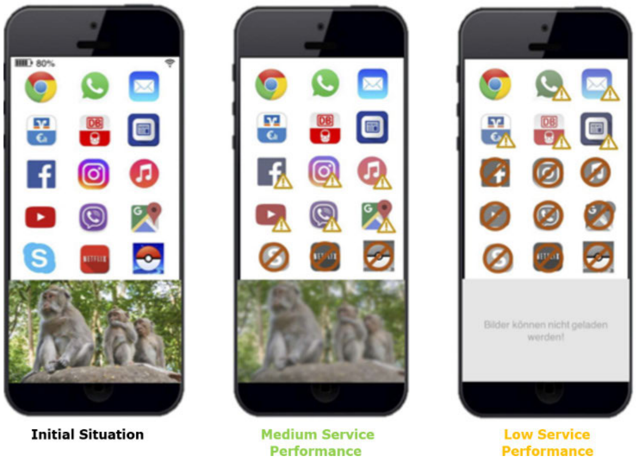

FIGURE 3. Remaining service performance.

TABLE 2. Attributes and attribute levels.

Attributes	Range	Levels
Current Situation of Receiver	Level 1 Level 2	No service Low service performance
Relationship to Receiver	Level 1 Level 2 Level 3 Level 4	Family/ Partner Friend Acquaintance Stranger
Additional Battery Consumption	Level 1 Level 2 Level 3	5 % 10 % 15 %
Remaining Service Performance	Level 1 Level 2	Medium service performance Low service performance

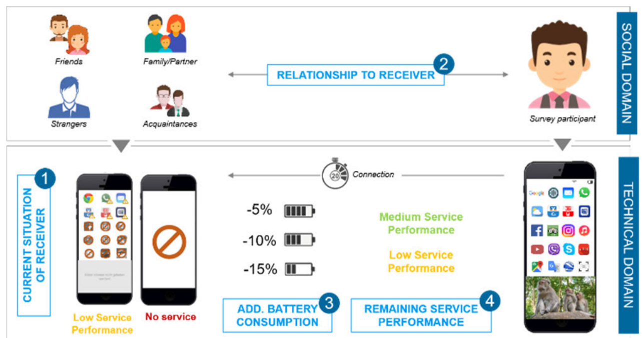

FIGURE 4. Attributes in the social and the technical domain.

the Internet connection and include the *remaining service performance* as a second cost-relevant factor in our study.

We assume that the forwarder is in a full-service initial situation in which all apps can be used without restrictions. During forwarding, the service performance of the forwarder is downgraded to *medium service performance* or *low service performance*. When downgraded to the *medium service performance* level, the forwarder experiences a restriction in using high-demand functions such as online games or virtual reality services. In addition, many social media apps, which are used massively by some users and are of high importance for them, are only accessible with reduced performance. Depending on the app, pictures are displayed blurry, or the loading times of new content are longer when scrolling. However, the user can still use apps for browsing, messaging, e-mailing, navigating, or banking without any restrictions. These apps are particularly important for many users because they are a constant companion in everyday life.

Equivalent to the level of *low service performance* of the attribute ''current situation of the receiver'', only the essential apps and functions are available to the user at this level, so almost all apps used for entertainment purposes are unusable. Helpful navigation, news, or banking tools cannot load graphical content, and communication services are reduced to exchanging purely text-based messages. These restrictions only apply temporarily for the time the forwarder provides an Internet connection to a receiver.

Fig. 3 gives a graphical overview of the restricted or unavailable apps in the attribute levels *medium service performance* and *low service performance*. In addition, the illustration also shows the full availability of all apps in the forwarder's initial situation to highlight the difference from the service restrictions. This figure was also shown to the study participants for better comprehension.

In summary, we define our technology based on four attributes and a total of eleven attribute levels, see Table 2. We divide the attributes of the CBC into the social domain and the technical domain, see Fig. 4. The social domain includes the *relationship to receiver*. The attributes *current situation of receiver, additional battery*, and *remaining service performance* are assigned to the technical domain.

Our survey consists of three parts. In the first part, we start with a questionnaire to gain insights into the usage behavior towards different apps on the one hand and the frequency and duration of interactions with different social groups on the other hand. In the second part, we introduce the D2D technology and the specific scenario in which the participant can become a forwarder by providing an Internet connection to a receiver. This is followed by the CBC experiment, which we use to elicit preferences for our presented technology. Finally, in the third part, we collect some personal and demographic characteristics.

We first begin our survey with a filter question. Only respondents who indicate that they own a smartphone can complete the survey, as owning a smartphone is a necessary precondition for participating in our technology. We then ask respondents about their usage patterns concerning the commonly used applications shown in Fig. 5. For a more detailed evaluation, we categorize these apps according to their functionality, from unidirectional communication such as mailing or messaging to high-demand entertainment services such as

Unidirectional Communication	Mailing, Messenger	
Bidirectional Communication	Internet and Video Telephony	
Web Information Services	Browsing, News, Weather, Sports	
Social Network Services	Social Media	
Streaming Services	Music, Video or Movie Streaming	
Database Services	Maps, Navigation	
Entertainment Services	Games, Augmented Reality (AR), Virtual Reality (VR)	

FIGURE 5. Frequently used apps classified by functionality.

online games or virtual reality services. Since providing an Internet connection to others leads to temporary limitations of one's smartphone performance, we assume that heavy smartphone users who frequently use high-demand apps are less willing to provide an Internet connection than users who use such app services less frequently.

We also ask our participants in the first part of the survey about the frequency and duration of personal encounters with other people. Based on these interaction patterns, we want to analyze the social contacts of the different social groups. Both the frequency of contacts and the duration which users spend in the transmission area of the different groups are interesting in this context. If users have frequent and long contact with particular social groups, towards which they also show a higher willingness to provide an Internet connection, this would be an important consideration for implementing socially-aware networks.

In the second part of the survey, we first introduce the D2D technology and the specific scenario to the participants. To convey all the necessary information while keeping complexity to a minimum, we designed the introductory text with an easy-to-understand reading style and graphical examples. We explain and summarize the *technology* with the following three key elements: First, our technology enables survey participants to provide an Internet connection to others in the vicinity via their smartphone without the network operator charging them additional costs or deducting data volume. Second, the Internet connection is established directly via the network operator and is secure so that third parties cannot read the data. Third, although the survey participants can improve someone else's Internet connection, they will have limited smartphone performance and require additional battery power.

We introduce the respondents to our study *scenario* with the following frame text:

> *'Now imagine that there are people from all the **social groups** presented (family, friends, acquaintances, strangers) in your immediate vicinity. Some of these people currently have no Internet connection at all or can only use a few apps (low service performance). If people still want to use the apps on their smartphones, they can send an automatic request to other people in the vicinity asking them to provide an Internet connection. Since you can currently use **all your apps without any restrictions**, you can now decide to help other people out and provide an Internet connection for **20 minutes**. This will allow the other person to use all the apps they want. The other person does not know if you declined or accepted the request. You will have an **increased battery consumption** of either 5%, 10%, or 15% during the existing connection. Additionally, you will have to **sacrifice service performance** and be downgraded to a lower level (medium service performance or low service performance).'*

Moreover, we place the respondents in the same initial artificial situation and endow them with a battery level of 80%. To determine the pure influence of social relations that is not biased by various effects of social pressure, we designed the experiment as a one-sided anonymous game so that the forwarder knows the identity of the receiver, but the receiver does not know from whom he or she receives the provided Internet connection. This anonymity is crucial because otherwise, the familiarity between the forwarder and the receiver may have an impact on the decision (see, e.g., [36], [38], [51]).

Since there are no monetary or other incentives for providing an Internet connection in our study, we assume that participants' behavior and choice decisions are based only on altruism. Furthermore, in the study, we refer to the receiver's need for help and the forwarder's ability to help others in the vicinity. Accordingly, the wording of the introductory text evokes possible altruistic behavior from respondents.

When designing the CBC, it is essential to ensure that the number of choice sets is not too small to avoid preference estimation errors and not too large so that respondents do not lose focus. Typically, such surveys take about 15-20 minutes to complete, so we chose to use 14 choice sets with a D-optimal ($2 \times 4 \times 3 \times 2$) fractional-factorial design following [52], which we preface with an example choice set to introduce the methodology. We use 12 of these choice sets for estimation and the remaining two choice sets as holdouts to assess predictive validity. Our choice sets consist of three technology alternatives from which participants must select their preferred option where they would most likely provide an Internet connection to the receiver. In addition, the respondent can also choose not to participate at all, which is represented by the no-choice option. Fig. 6 illustrates such a choice set. Different combinations of attribute levels in the three profiles are randomly selected within each choice set with minimal overlap. Our design thus conforms to typical recommendations for an appropriate CBC design, which should have between three to six profiles in a choice set [53]. Otherwise, with a much larger number of profiles, it becomes difficult for subjects to make a correct choice [54]. After the CBC experiment, we check participants' attention by asking two comprehension questions.

1 In which of these scenarios would you be most likely to provide an Internet connection?				
Current Situation of Receiver	No service	No service	Low service performance	I do not want to provide my Internet connection under any of these circumstances.
Relationship to Receiver	Friend	Acquaintance	Family/Partner	
Your additional battery consumption	-10%	-15%	-5%	
Your remaining service performance	Medium service performance	Low service performance	Medium service performance	
	○	○	○	○

FIGURE 6. Choice set example.

TABLE 3. Demographic distribution of respondents.

GENDER	AGE	EDUCATION LEVEL
Female (43%)	Under 20 (3%)	No school-leaving qual. (0%)
Male (57%)	20-24 (8%)	School-leaving qual. (3%)
	25-29 (8%)	Secondary school cert. (22%)
	30-34 (14%)	Higher school cert. (18%)
	35-39 (16%)	Completed apprenticeship (30%)
	40-44 (8%)	Completed higher edu. (27%)
	45-49 (9%)	
	50-54 (9%)	
	55-59 (8%)	
	60-64 (3%)	
	65-70 (13%)	

n = 181

In the online survey's third and final part, we intend to gain further insights into the participants' characteristics, especially regarding our formulated hypotheses. For this purpose, we determine the attitudes of our respondents using a five-point Likert scale within the framework of eight items for the construct *altruism (H2)* based on Costa and MacCrae [55] and four items for the construct *technology anxiety (H3)* based on Meuter *et al.* [56] and Raub [57]. Furthermore, we collect demographic data such as age, gender, and education level to obtain an evenly distributed demographic structure. Additionally, we include further questions on daily smartphone usage time, general battery consumption, and available data volume per month to better understand the importance of smartphones for the respondents.

IV. RESULTS OF THE EMPIRICAL STUDY

A. DATA SET

We engaged a market research company that selected a representative sample of the German population regarding age and gender. We received 181 completed questionnaires that passed the comprehension checks and were used for further analysis. Table 3 shows the demographic distribution of our sample, which is sufficiently large for a good evaluation according to common guidelines for CBC experiments.

B. SMARTPHONE & APP USAGE

The results on smartphone and app usage in Fig. 7 show that most respondents use various mobile data services at least weekly. This indicates familiarity and a minimum level of

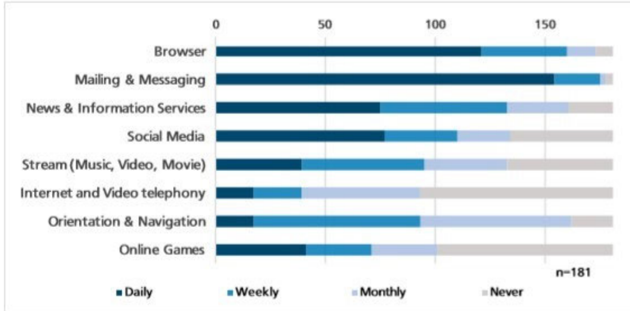

FIGURE 7. Usage frequency of different mobile data services.

TABLE 4. Correlation between frequency and intra-contact times of social groups.

	Family/ Partner	Close Friends	Friends from Work/Uni	Club Members	Acquaintances from Work/Uni
CORR	0.189	0.259	0.612	0.608	0.664
p-Value	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001

experience with their smartphone device. From the frequent use of mailing and messaging as well as social media services, we conclude the high importance of connectivity with others in the social environment.

C. SOCIAL ACTIVITIES

In analyzing social activities from the first part of the survey, the previously defined social groups were further divided to improve respondents' comprehensibility. Accordingly, respondents can distinguish, for example, between club members (e.g., sports club, gym, theater group) and work colleagues or fellow students from their group of acquaintances or their friends.

The evaluation shows that people meet more often with people with whom they have a closer relationship. Moreover, the duration of the individual encounters provides further information about the potential for forwarding data packets. On the one hand, longer durations allow more data to be forwarded; on the other hand, frequent and short encounters improve network structure mobility, allowing more opportunities to establish connections to several different devices. The reported average duration of each encounter exceeds the 20-minutes scenario in the survey. Interestingly, significant differences emerge in the segmentation of social groups in terms of friends and acquaintances. In particular, professional life contacts, i.e., work colleagues or fellow students, lead to longer intra-contact times. We calculate the correlation coefficient to examine the relationship between frequency and intra-contact times for each social group (see Table 4).

We observe a significant positive relationship between meeting frequency and duration of contact times for all social groups. Especially for contacts from professional life and acquaintances in general, this positive correlation is quite strong. However, the correlation for the family and friends groups is somewhat lower, which could be because most respondents see their friends every day, but these encounters tend to occur in the morning and evening hours and are therefore limited in terms of duration. The same applies to friendships in private life, as these encounters in leisure time are mostly limited to a few hours. In contrast, professional life contacts are not uncommon for up to eight hours during the working day. Nevertheless, the correlation shows a positive relationship for all contact types. Respondents have frequent encounters with people in all social groups and are also within their transmission range for a sufficient amount of time, so the potential for establishing D2D communication exists in all social groups.

D. CBC ANALYSIS

For the evaluation of the CBC, we follow the utility-theoretic approach of Thurstone [58]. Thus, we assume that respondent h chooses option i with the highest utility $u_{h,i}$. Here, the total utility contains a deterministic and a stochastic part: $u_{h,i} = v_{h,i} + \varepsilon_{h,i}$. The stochastic part $\varepsilon_{h,i}$ contains unobservable behavior for which we assume an extreme value distribution that has a functional form similar to the normal distribution. In contrast, the deterministic part $v_{h,i}$ holds observable information, such as the attributes and levels represented in the choice sets.

We use an additive model for the utility of a product alternative, i.e., $v_{h,i} = \beta_h \cdot X_i$, where β_h is a vector of the respondent's preferences h for all attributes and the vector X_i indicates the attribute levels of each attribute in the product i [59]. In alignment with Gensler *et al.* [60], we estimate the probability $\Pr_{h,a}(i)$ that respondent h selects an option i as the preferred alternative from the set of alternatives I_a for each choice set a :

$$\Pr_{h,a}(i) = \frac{\exp(\mathrm{v_{h,i}})}{\exp\left(\mathrm{v_{h,0}}\right) + \sum_{\mathrm{i}' \in I_a} \exp(\mathrm{v_{h,i'}})}$$

In this equation, $v_{h,i}$ is the utility of product i for consumer h and $v_{h,0}$ is the utility of the no-choice option for consumer h. For the estimation of the individual-level parameters from the choice-based conjoint analysis data, we employ Hierarchical Bayes (HB). Based on the assumption of high consistency in decision making, HB is known to estimate part-worth very accurately for single attribute values, whereas a small number of choice sets per respondent is already sufficient (see, e.g., [45]).

Accordingly, for the evaluation of our CBC experiment, we estimate the parameter values (see Table 5) and derive the importance weights for the attributes of our study (see Fig. 8). The signs and magnitudes of the parameter values are consistent and reasonable, indicating high eye validity. For example, low additional battery consumption confers higher utility compared to high battery consumption.

In addition, we consider the proportion of correctly predicted decisions based on the first-choice model to assess the validity of our results further. We calculate the internal validity, which is a general quality criterion for empirical studies, and provides information on how accurately the measures of the independent variable explain the dependent variable or outcome. We also specify predictive validity, and thus the extent to which the model can predict the service configuration chosen by a respondent. The internal validity is 88.26%, and the predictive validity is 76.80%, so we can assume that our model has sufficient sample quality and good explanatory power.

The average importance weights in Fig. 8 show that the *relationship to receiver* is by far the most important attribute with 63.41%. Table 5 shows the ranking of the attribute levels according to the preferences elicited in the survey,

TABLE 5. Parameter estimates of CBC study.

Attribute	Attribute Level	Parameter Value	Std. Dev.
Constant		1.75	4.90
Current Situation of Receiver	No service	0.15	0.56
	Low service performance	-0.15	0.56
Relationship to Receiver	Family/Partner	3.48	2.34
	Friend	1.07	0.81
	Acquaintance	-1.60	1.16
	Stranger	-2.95	1.67
Additional Battery Consumption	5 %	0.08	0.55
	10 %	0.18	0.36
	15 %	-0.26	0.64
Remaining Service Performance	Medium service performance	0.40	0.58
	Low service performance	-0.40	0.58

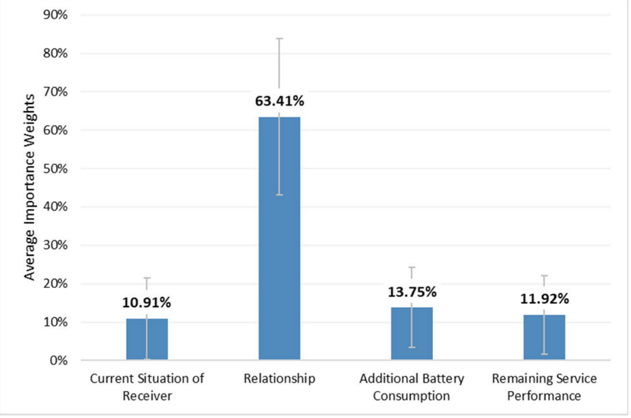

FIGURE 8. Average importance weights.

with the distance between the levels providing information about user preferences. Since the sum of all parameter values of an attribute always results in a value of zero according to the evaluation method we used, negative parameter values thus do not necessarily mean that respondents associate a negative utility with these attribute values. Instead, they illustrate a lower preference for attribute levels with lower parameter values. Even the attribute level with the lowest parameter value can still provide a benefit to users. For the attribute *relationship to receiver*, as expected, we observe the highest parameter values for family/partner (3.48), followed by friends (1.07) and acquaintances (−1.60). The technology is rated worst when strangers are in the receiving role (−2.95). Between friends and acquaintances, the largest drop in parameter values occurs with a difference of −2.67 compared to −2.41 between family/partner and friends and −1.35 between acquaintances and strangers. The perceived gain in utility for the forwarder when the receiver is a friend instead of an acquaintance is thus much higher than the additional utility when the receiver is an acquaintance instead of a stranger or belongs to the family/partner group instead of friends.

These results support Hypothesis 1 (*Social Relationship*), which states that individuals are more willing to act as forwarders for people with whom they have a stronger social relationship and with whom trust has already been established. The high importance weight indicates that relationship is the main decision criterion with respect to participation as a forwarder in our technology. Accordingly, our participants are rather willing to act as forwarders for people from the family/partner and friends social groups, regardless of the constraints. Nevertheless, we also observe the highest standard deviation (20%) for this attribute, indicating heterogeneous preferences among respondents.

Additional battery consumption (13.75%) is the second most important attribute with a massive gap to *relationship to receiver*, closely followed by *remaining service performance* (11.92%) and *current situation of receiver* (10.91%) so that these three attributes play a similar role in the decision process, which is significantly lower compared to the relationship attribute.

Surprisingly, our evaluation yields the highest parameter value for *additional battery consumption* of 10% (0.18), followed by 5% (0.08), whereas the largest additional consumption of 15% (−0.26) is perceived as the worst. We can possibly attribute these results to our scenario in which the attribute of additional battery consumption plays a comparatively minor role. Indeed, previous research suggests battery level as one of the most critical drivers of selfish behavior [27]. In contrast, as expected, participants are less willing to act as forwarders if they have to accept more significant restrictions in return. Thus, we see a parameter value of 0.40 for medium service performance as *remaining service performance* for the forwarder and -0.40 for low service performance. Moreover, our results show that the willingness to provide an Internet connection is higher when the *current situation of receiver* is more of an emergency and has no service at all (0.15) compared to low service performance (−0.15).

TABLE 6. Aggregated choice decisions.

Participation choices	81.85%
No-Choice option choices	18.15%
Respondents who always participate	58.01%
Respondents who never participate	8.29%

Table 6 presents the aggregate number of participation choices and no-choice options. We observe that in 81.85% of all choice sets, respondents choose one of the three alternatives presented and thus would act as forwarders. Correspondingly, in 18.15% of the cases, respondents choose not to participate in any technology alternatives and thus choose the no-choice option. We also find that 58.01% of our respondents always choose one of the technology options, and only 8.29% of the sample never wants to participate in the technology and thus always chooses the no-choice option.

These results show that our presented D2D technology is attractive and realistic, as many of our respondents can imagine participating in our technology and acting as forwarders. This is remarkable considering that there are no compensation payments or similar incentives for participants in our presented scenario. Moreover, the low numbers regarding the choice of the no-choice option show that we used the right design for our study regarding the CBC method and the selection of attributes and attribute levels. To better understand the selection of the no-choice option, we asked our respondents at the end of the CBC experiment which reasons were decisive for them if they did not select any of the options in at least one of the choice sets. Although we mentioned that all forwarded data are secured and inaccessible to third parties in the explanation of the technology, data security was given as an answer several times. Accordingly, further development of D2D communication should pay special attention to this concern and also advertise it.

E. HYPOTHESES EVALUATIONS

In the following, we consider the three hypotheses formulated in sections B and C and evaluate the survey's personality questions for this purpose.

Hypothesis 1 (*Social Relationship*) is already supported by the high importance weight of the relationship attribute for the decision to act as forwarders. Specifically, the parameter values show that stronger relationships (i.e., families/partners and friends) positively affect the decision to participate in technology.

The second hypothesis (*Altruism*) is based on the assumption that altruism mitigates situational costs such as additional battery consumption and remaining service in our scenario. The respondent's participation decision depends primarily on the respondent's altruistic attitude and social relationship with the receiver. On the one hand, the aggregated choice

TABLE 7. Correlation analysis.

	Current Situation of Receiver	Relation-ship to Receiver	Additional Battery Consumption	Remaining Service Performance
ALTRUISM				
CORR	-0.24	0.27	-0.21	-0.08
p-Value	p<0.001	p<0.001	p<0.001	0.299
TECHNOLOGY ANXIETY				
	None-Incidence			
CORR	-0.828			
p-Value	0.162			

TABLE 8. Segmentation analysis.

CATEGORY	Current Situation of Receiver	Relation-ship to Receiver	Additional Battery Consumption	Remaining Service Performance
SMARTPHONE USAGE BEHAVIOR				
Heavy (n=101)	12.2%	61.1%	15.3%	11.4%
Weak (n=80)	9.2%	66.3%	11.9%	12.6%
p-Value	p<0.05	p<0.05	p<0.05	0.24
SOCIAL BEHAVIOR				
Frequent (n=54)	12.8%	60.1%	15.3%	11.8%
Occasional (n=127)	10.1%	64.8%	13.1%	12.0%
p-Value	0.11	0.15	0.20	0.92
GENDER				
Men (n=104)	11.1%	64.1%	13.4%	11.4%
Women (n=77)	10.6%	62.5%	14.3%	12.6%
p-Value	0.73	0.61	0.56	0.44
AGE				
Young (n=40)	10.5%	56.5%	18.0%	15.0%
Older (n=141)	11.0%	65.4%	12.6%	11.0%
p-Value	0.79	p<0.01	p<0.01	p<0.05

decisions in Table 6 already show a high willingness of respondents to provide an Internet connection. On the other hand, the correlation analysis based on the personality questions in the third part of the online survey presented in Table 7 shows significant negative correlations for the attributes *current situation of receiver* and *additional battery consumption*, and a significant positive correlation with the attribute *relationship to receiver*. Therefore, the results partially support hypothesis 2.

For hypothesis 3 (*Technology Anxiety*), we analyze the possible influence of technology anxiety on rejection and nonparticipation in our technology. To do this, we calculate the correlation coefficient between the derived value for technology anxiety and the frequency of selecting the no-choice option for each respondent, as also summarized in Table 7. The results show a nonsignificant negative correlation close to zero, so hypothesis 3 is not supported. Apparently, despite their technology anxiety, users are equally willing to act as forwarders and provide an Internet connection to potential receivers as people who are comfortable with technology.

The results show that the presented social aspects play a central role in the decision process to participate in D2D communication as a forwarder. Furthermore, the importance of distinguishing between the individual behavior is highlighted, which in turn challenges the joint consideration of purely selfish or cooperative behavior in the existing literature. With this in mind, exploiting social structures and relationships between individuals could be a promising approach to improve the acceptance and frequent usage of D2D communication.

F. SEGMENTATION ANALYSIS

As previously mentioned, the standard deviations of the importance weights are substantial in some cases. However, to appropriately design services within D2D communication, it is vital to recognize how specific attributes can influence the decisions of potential users, thereby possibly causing a shift in preferences for specific attributes.

To better interpret the results in combination with the identified preferences, we sequentially divide respondents into two groups according to their reported smartphone usage, social behavior, gender, and age. In doing so, we examine whether participants with certain characteristics (e.g., heavy smartphone users) differ in their attribute ratings compared to the other group (e.g., weak smartphone users). We present the results in Table 8.

First, we divide the respondents into *heavy smartphone users* and *weak smartphone users* according to their overall smartphone usage and frequency of use for different apps. We calculate the average importance weights for these two segments and find significant differences for three attributes at the 5% level. In particular, heavy smartphone users show stronger preferences for the attributes current situation of receiver and additional battery consumption, whereas weak smartphone users tend to rate the relationship factor higher. Perceptions of remaining service performance, in contrast, showed no significant difference.

In the following segmentation, we examine whether individuals who maintain frequent and many social contacts behave differently in the context of D2D communication. According to the data on the frequency of contact, daily encounters, and the sum of intra-contact times, we divide the respondents into *frequent socializers* and *occasional socializers* and calculate the corresponding average importance weights. Although these values differ, we cannot detect any significant difference between the two groups. This implies independence of preferences from the respondents' social behavior or potential D2D users, so we can also assume an acceptance of D2D communication independent of social behavior. From a technical point of view, higher mobility and longer interaction times are, of course, beneficial for improved network performance.

Finally, we split the data with respect to respondents' demographic characteristics - i.e., gender and age - to provide potentially valuable insights for marketing purposes, field testing, and ultimately broad adoption of the technology. Separation into *male* and *female* respondents yields no significant differences. In the next step, we segment the sample based on the age factor, with respondents between the ages of 18 and 30 representing a *young age group* and those over 30 being classified as an *older age group*. This segmentation leads to statistically significant differences in three importance weights. Essentially, respondents in the older age group rate the social relationship as considerably more important and are more willing to sacrifice their battery consumption. These results are consistent with the findings from the segmentation based on smartphone usage behavior. However, this is not surprising as younger individuals tend to use their smartphones to a greater extent than older individuals. Accordingly, there is a certain degree of correspondence between the young age group and weak smartphone users and the older age group and heavy smartphone users. Moreover, the impact on one's device has significantly stronger importance for younger respondents than older respondents. For further investigation, we show a more detailed representation of the utility values for each attribute level of the relationship in Fig. 9.

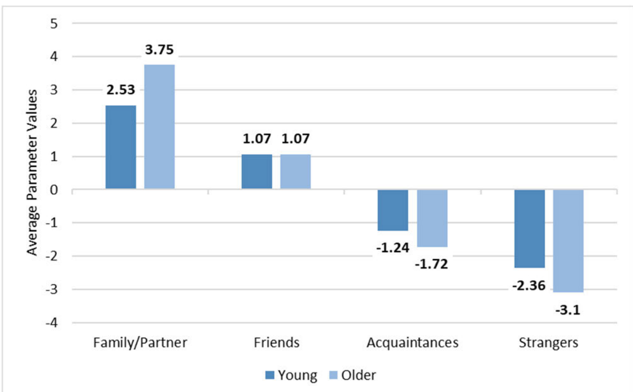

FIGURE 9. Average parameter values for "social relationship" by age groups.

Whereas the values for friends are similar in both age groups, we observe that the younger age group has much lower parameter values for family/partner, acquaintances, and strangers than the older age group. One reason for this could be the higher proportion of social media users in the younger age group, and thus a more substantial need to always stay connected. Whereas these findings, ceteris paribus, do not justify immediate customer segmentation, it is advisable to carefully consider possible implications for the technical implementation. This becomes particularly important against the background of integrating complex computing tasks or caching large files.

Overall, these results do not imply strongly divergent or contradictory perceptions for the different groups considered. Nevertheless, heavy smartphone users and younger users have stronger preferences for additional battery consumption. This fact should be taken into account in forwarder-receiver matching so that these groups are more likely to serve as forwarders at a lower distance and in connections with lower throughput so that the battery is not too heavily burdened. Since younger users also consider their remaining service performance to be more important than older users, the service of the forwarder should also be restricted as little as possible by matching. Since weak smartphone users and older users attach greater importance to the relationship to the receiver, more cost-intensive connections (e.g., due to greater distance or more data throughput) can be established by these groups if they have a close relationship to the receiver. Finally, heavy smartphone users care more about the receiver's situation, so this group should rather provide Internet connections to receivers with no service connection, as there is a greater willingness to do so.

V. DISCUSSION AND CONCLUSION

In this paper, we investigate the influence of various attributes on the decision to participate in D2D communication as a forwarder, providing Internet connection to others. D2D communication enables network operators to cope with increasing mobile data traffic by offloading data to more flexible network structures, thus enabling performance benefits. Essential to the success of D2D communication is the willingness of users to participate, as the technology can only be successful if many users participate and are willing to act as forwarders. Therefore, we conduct a CBC analysis to elicit users' preferences and evaluate them on a segment-specific basis.

With our study, we contribute to theory and practice. Whereas existing approaches mainly focus on the implementation and technical challenges of D2D communication, we choose a purely user-centric approach. We conduct a user study in the context of D2D communication in a scenario without incentives and thus investigate purely altruistic motives. As far as we know, we are the first to conduct a user study in this context and gain insights into user preferences for D2D technologies. From a theoretical perspective, we extend the existing literature on D2D communication in a meaningful direction

We gain insights into preferences for D2D communication and the importance of different attributes. In particular, our results show the great importance of social relationships in the decision process of acting as forwarders for others. With an importance weighting of 63.41%, this attribute can even compensate or outweigh potential constraints, as the other three attributes, additional battery consumption (13.75%), remaining service performance (11.92%), and situation of receiver (10.91%), are far less important to participants.

Thus, we outline that the social relationship between forwarder and receiver is essential in implementing the technology. Moreover, our results indicate that the success of D2D communication does not necessarily depend on appropriate incentives, as assumed by many studies. Instead, with the right design and implementation of such a technology, altruistic motivation is sufficient for many users to provide

Internet connection to other people, mainly family members and friends, and to suffer losses themselves in return.

As academia and industry are trying to explore the social aspects in many communication technologies [11], our results also provide essential guidance for the advancement of D2D communication. To increase user acceptance and willingness to participate, the receiver's social relationships with potential forwarders in the environment should be included in the algorithm that matches the two parties.

Moreover, developers should continue to work on the technical attributes and, to this end, integrate our findings and consider them for future developments of D2D communication. For example, on the one hand, developers should continue improving the energy efficiency of such communication. On the other hand, consideration of the current battery status when selecting appropriate forwarders is also conceivable. Some respondents indicate that battery consumption is of great importance to them. For this group, network operators need to think carefully about which services they want to offer within D2D communication, as some services might be too costly in terms of resource consumption. In addition, it would be conceivable to take into account the usage habits of receivers with regard to the services used, so that a forecast for the expected additional battery consumption for the forwarder can be made depending on the intensity of use and the type of apps usually used by a receiver.

There is also further potential for development concerning the forwarder's remaining service performance. In situations when the forwarder does not need to access performance-intensive applications, more massive impacts and greater restrictions on remaining service performance may be acceptable from the forwarder's perspective. However, if the forwarder wants or needs to access all of its applications, including high-demand entertainment services such as augmented reality apps, the restriction on remaining service performance may be perceived as more severe.

Possible solutions can be divided into two approaches: First, priorities could be assigned to the forwarding device to ensure that forwarders can access the services they need on their smartphones at all times. Accordingly, only a highly limited Internet connection would be provided to the receiver. However, this approach leads to additional overhead, since on the one hand, the connection between the base station and forwarder should remain as extensive as possible, and on the other hand, a reliable connection between forwarder and receiver must be ensured so that the receiver can use a minimum of services.

A second approach, but with apparent disadvantages for the receiver, could be to limit the possible service performance for the receiver to low-demand applications that place only a medium or almost no load on the forwarding device. In this case, it is questionable whether implementation of D2D communication would still be helpful at all. More advanced ideas could focus on a balance between these two approaches and build context- or application-aware scheduling that considers the exact usage behavior of the forwarding user. Moreover, CBC results show that the willingness to act as a forwarder increases, the worse the receiver's initial situation is. This effect could be technically implemented so that the receivers' current situation is taken into account in the service distribution so that users with comparatively poor connections are given preference (priority scheduling).

Further analyses show that trust is the main decision driver, whereas the altruistic characteristics of a survey participant have only partial explanatory power. Technology affinity, on the other hand, does not seem to have a significant influence. However, some of the standard deviations are quite large, suggesting heterogeneous preferences. Hence, we perform various segmentations of respondents and find some significant differences in terms of smartphone usage behaviors and age of respondents, with these factors presumably strongly related to each other. Accounting for the corresponding preferences in forwarder-receiver matching, such as the higher battery sensitivity of heavy smartphone users and younger users, or the stronger preference of weak smartphone users and older users for the relationship to the receiver, may increase acceptance and willingness to participate in the technology.

Whereas these results provide a good starting point for further and more detailed research, our study also has some limitations, both from the general research process and from the results within the obtained dataset. First, we use an online survey, which is a very anonymous environment. Respondents might behave differently if confronted with a more realistic environment and actual devices. However, a field experiment with our scenario is challenging to conduct. Second, we surveyed a German sample, so generalizations to other countries or cultural backgrounds may be limited.

In terms of future research, the findings presented above can form the basis for using and integrating realistic social structures and improve network performance based on individual preferences. In addition, incentive mechanisms that we do not consider in our study setup may increase the willingness to provide Internet connections. On the one hand, these external incentives may influence connections with strangers or acquaintances, but on the other hand, they may also influence connections with people who maintain social ties, e.g., friends or family members. Of course, these systems can also consider all cost- and performance-related factors to design the network topology and efficiently distribute the required traffic.

REFERENCES

[1] *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2017–2022*, Cisco, San Jose, CA, USA, 2019.

[2] F. Jameel, Z. Hamid, F. Jabeen, S. Zeadally, and M. A. Javed, "A survey of device-to-device communications: Research issues and challenges," *IEEE Commun. Surveys Tuts.*, vol. 20, no. 3, pp. 2133–2168, Jul. 2018.

[3] Y. Chen, S. He, F. Hou, Z. Shi, and J. Chen, "An efficient incentive mechanism for device-to-device multicast communication in cellular networks," *IEEE Trans. Wireless Commun.*, vol. 17, no. 12, pp. 7922–7935, Dec. 2018.

[4] L. Wang, S. Liu, M. Chen, G. Gui, and H. Sari, "Sidelobe interference reduced scheduling algorithm for mmWave device-to-device communication networks," *Peer-Peer Netw. Appl.*, vol. 12, no. 1, pp. 228–240, Jan. 2019.

[5] F. S. Shaikh and R. Wismuller, "Routing in multi-hop cellular device-to-device (D2D) networks: A survey," *IEEE Commun. Surveys Tuts.*, vol. 20, no. 4, pp. 2622–2657, Oct. 2018.
[6] O. Hayat, R. Ngah, and Y. Zahedi, "In-band device to device (D2D) communication and device discovery: A survey," *Wireless Pers. Commun.*, vol. 106, no. 2, pp. 451–472, May 2019.
[7] Y. Chen, B. Ai, Y. Niu, R. He, Z. Zhong, and Z. Han, "Resource allocation for device-to-device communications in multi-cell multi-band heterogeneous cellular networks," *IEEE Trans. Veh. Technol.*, vol. 68, no. 5, pp. 4760–4773, May 2019.
[8] W. Mwashita and M. O. Odhiambo, "Interference management techniques for device-to-device communications," in *Predictive Intelligence Using Big Data and the Internet of Things*. Hershey, PA, USA: IGI Global, 2019, pp. 219–245.
[9] Y. Lv, "Security issues in multi-hop device-to-device communication networks—Secure routing protocols solution," *J. Phys., Conf. Ser.*, vol. 1828, no. 1, Feb. 2021, Art. no. 012117.
[10] N. Zabetian, A. Mohammadi, and M. Masoudi, "Energy-efficient power allocation for device-to-device communications underlaid cellular networks using stochastic geometry," *Trans. Emerg. Telecommun. Technol.*, vol. 30, no. 12, p. e3768, Dec. 2019.
[11] M. Ahmed, Y. Li, M. Waqas, M. Sheraz, D. Jin, and Z. Han, "A survey on socially aware device-to-device communications," *IEEE Commun. Surveys Tuts.*, vol. 20, no. 3, pp. 2169–2197, 3rd Quart., 2018.
[12] U. N. Kar and D. K. Sanyal, "An overview of device-to-device communication in cellular networks," *ICT Exp.*, vol. 4, no. 4, pp. 203–208, Dec. 2017.
[13] METIS. (2013). *Scenarios, Requirements and KPIs for 5G Mobile and Wireless System*. Accessed: Jun. 11, 2021. [Online]. Available: https://cordis.europa.eu/docs/projects/cnect/9/317669/080/deliverables/001-METISD11v1pdf.pdf
[14] A. Balachandran, V. Aggarwal, E. Halepovic, J. Pang, S. Seshan, S. Venkataraman, and H. Yan, "Modeling web quality-of-experience on cellular networks," in *Proc. 20th Annu. Int. Conf. Mobile Comput. Netw.*, Sep. 2014, pp. 213–224.
[15] M. Fiedler, T. Hossfeld, and P. Tran-Gia, "A generic quantitative relationship between quality of experience and quality of service," *IEEE Netw.*, vol. 24, no. 2, pp. 36–41, Mar./Apr. 2010.
[16] Z. Zhang, Y. Wu, X. Chu, and J. Zhang, "Energy-efficient transmission rate selection and power control for relay-assisted device-to-device communications underlaying cellular networks," *IEEE Wireless Commun. Lett.*, vol. 9, no. 8, pp. 1133–1136, Aug. 2020.
[17] B. Singh, Z. Li, and M. A. Uusitalo, "Flexible resource allocation for device-to-device communication in FDD system for ultra-reliable and low latency communications," in *Proc. Adv. Wireless Opt. Commun. (RTUWO)*, Nov. 2017, pp. 186–191.
[18] K. Vanganuru, S. Ferrante, and G. Sternberg, "System capacity and coverage of a cellular network with D2D mobile relays," in *Proc. IEEE Mil. Commun. Conf. (MILCOM)*, Oct. 2012, pp. 1–6.
[19] Y. Yoo and D. Agrawal, "Why does it pay to be selfish in a MANET?" *IEEE Wireless Commun.*, vol. 13, no. 6, pp. 87–97, Dec. 2006.
[20] C. Gao, H. Zhang, X. Chen, Y. Lin, D. Jin, and S. Chen, "Impact of selfishness in device-to-device communication underlying cellular networks," *IEEE Trans. Veh. Technol.*, vol. 66, no. 10, pp. 9338–9349, Oct. 2017.
[21] S. Basagni, M. Conti, S. Giordano, and I. Stojmenovic, *Mobile Ad Hoc Networking: The Cutting Edge Directions*, 35th ed. Hoboken, NJ, USA: Wiley, 2013.
[22] M. Abolhasan, M. Abdollahi, W. Ni, A. Jamalipour, N. Shariati, and J. Lipman, "A routing framework for offloading traffic from cellular networks to SDN-based multi-hop device-to-device networks," *IEEE Trans. Netw. Service Manage.*, vol. 15, no. 4, pp. 1516–1531, Dec. 2018.
[23] Q. Liang and Q. Ren, "Energy and mobility aware geographical multipath routing for wireless sensor networks," in *Proc. IEEE Wireless Commun. Netw. Conf.*, vol. 3, Mar. 2005, pp. 1867–1871.
[24] P. Hui, J. Crowcroft, and E. Yoneki, "BUBBLE rap: Social-based forwarding in delay-tolerant networks," *IEEE Trans. Mobile Comput.*, vol. 10, no. 11, pp. 1576–1589, Nov. 2011.
[25] S. Gaito, E. Pagani, and G. P. Rossi, "Strangers help friends to communicate in opportunistic networks," *Comput. Netw.*, vol. 55, no. 2, pp. 374–385, Feb. 2011.
[26] Y. Zhao and W. Song, "Survey on social-aware data dissemination over mobile wireless networks," *IEEE Access*, vol. 5, pp. 6049–6059, 2017.
[27] L. Buttyán and J.-P. Hubaux, "Stimulating cooperation in self-organizing mobile ad hoc networks," *Mobile Netw. Appl.*, vol. 8, no. 5, pp. 579–592, 2003.
[28] X. Fang, T. Zhang, Y. Liu, G. Y. Li, and Z. Zeng, "Multi-winner auction based mobile user caching in D2D-enabled cellular networks," in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2019, pp. 1–6.
[29] B. F. Meeker, "Decisions and exchange," *Amer. Sociol. Rev.*, vol. 36, no. 3, 1971.
[30] W. D. Hamilton, "The genetical evolution of social behaviour. I," *J. Theor. Biol.*, vol. 7, no. 1, pp. 17–52, 1964.
[31] Z. Wang, J. Liu, and W. Zhu, "Social-aware video delivery: Challenges, approaches, and directions," *IEEE Netw.*, vol. 30, no. 5, pp. 35–39, Sep./Oct. 2016.
[32] E. L. Glaeser, D. I. Laibson, J. A. Scheinkman, and C. L. Soutter, "Measuring trust," *Quart. J. Econ.*, vol. 115, no. 3, pp. 811–846, 2000.
[33] L. van de Wijngaert and H. Bouwman, "Would you share? Predicting the potential use of a new technology," *Telematics Inform.*, vol. 26, no. 1, pp. 85–102, Feb. 2009.
[34] N. K. Malhotra, S. S. Kim, and J. Agarwal, "Internet users' information privacy concerns (IUIPC): The construct, the scale, and a causal model," *Inf. Syst. Res.*, vol. 15, no. 4, pp. 336–355, Dec. 2004.
[35] J. Fogel and E. Nehmad, "Internet social network communities: Risk taking, trust, and privacy concerns," *Comput. Hum. Behav.*, vol. 25, no. 1, pp. 153–160, Jan. 2009.
[36] E. Hoffman, K. McCabe, and V. Smith, "Social distance and other-regarding behavior in dictator games," *Amer. Econ. Rev.*, vol. 86, no. 3, pp. 653–660, 1996.
[37] S. H. Schwartz, "Normative influences on altruism," *Adv. Exp. Soc. Psychol.*, vol. 10, no. 1, pp. 221–279, 1977.
[38] C. C. Eckel and P. J. Grossman, "Altruism in anonymous dictator games," *Games Econ. Behav.*, vol. 16, no. 2, pp. 181–191, Oct. 1996.
[39] J. Lu, J. E. Yao, and C.-S. Yu, "Personal innovativeness, social influences and adoption of wireless internet services via mobile technology," *J. Strategic Inf. Syst.*, vol. 14, no. 3, pp. 245–268, Sep. 2005.
[40] F. D. Davis, R. P. Bagozzi, and P. R. Warshaw, "User acceptance of computer technology: A comparison of two theoretical models," *Manage. Sci.*, vol. 35, pp. 982–1003, Aug. 1989.
[41] B. Ovčjak, M. Heričko, and G. Polančič, "Factors impacting the acceptance of mobile data services—A systematic literature review," *Comput. Hum. Behav.*, vol. 53, pp. 24–47, Dec. 2015.
[42] J. J. Louviere, D. A. Hensher, and J. D. Swait, *Stated Choice Methods: Analysis and Applications*. Cambridge, U.K.: Cambridge Univ. Press, 2000.
[43] J. Swait and R. L. Andrews, "Enriching scanner panel models with choice experiments," *Marketing Sci.*, vol. 22, no. 4, pp. 442–460, Nov. 2003.
[44] K. Keller, C. Schlereth, and O. Hinz, "Sample-based longitudinal discrete choice experiments: Preferences for electric vehicles over time," *J. Acad. Marketing Sci.*, vol. 49, no. 3, pp. 482–500, May 2021.
[45] H. Al-Shatri, K. Keller, F. Jacobfeuerborn, O. Hinz, and A. Klein, "Eliciting and considering underlay user preferences for data-forwarding in multihop wireless networks," *IEEE Access*, vol. 7, pp. 40052–40067, 2019.
[46] R.-I. Ciobanu, C. Dobre, M. Dascălu, Ş. Trăuşan-Matu, and V. Cristea, "SENSE: A collaborative selfish node detection and incentive mechanism for opportunistic networks," *J. Netw. Comput. Appl.*, vol. 41, pp. 240–249, May 2014.
[47] P. Hui, K. Xu, V. O. K. Li, J. Crowcroft, V. Latora, and P. Lio, "Selfishness, altruism and message spreading in mobile social networks," in *Proc. IEEE INFOCOM Workshops*, Apr. 2009, pp. 1–6.
[48] C. Bermejo, R. Zheng, and P. Hui, "An empirical study of human altruistic behaviors in opportunistic networks," in *Proc. 7th Int. Workshop Hot Topics Planet-Scale Mobile Comput. Online Social Netw. (HOTPOST)*, 2015, pp. 43–48.
[49] L. Pelusi, A. Passarella, and M. Conti, "Opportunistic networking: Data forwarding in disconnected mobile ad hoc networks," *IEEE Commun. Mag.*, vol. 44, no. 11, pp. 134–141, Nov. 2006.
[50] M. V. Phong, T. T. Nguyen, H. V. Pham, and T. T. Nguyen, "Mining user opinions in mobile app reviews: A keyword-based approach (T)," in *Proc. 30th IEEE/ACM Int. Conf. Automated Softw. Eng. (ASE)*, Nov. 2015, pp. 749–759.
[51] I. Bohnet and B. S. Frey, "The sound of silence in prisoner's dilemma and dictator games," *J. Econ. Behav. Org.*, vol. 38, no. 1, pp. 43–57, Jan. 1999.
[52] D. J. Street and L. Burgess, *The Construction of Optimal Stated Choice Experiments: Theory and Methods*. Hoboken, NJ, USA: Wiley, 2007.
[53] *Sawtooth Software Lighthouse Studio Help*. Accessed: May 26, 2021. [Online]. Available: https://www.sawtoothsoftware.com/help/lighthouse-studio/manual/hid_web_cbc_designs_4.html

[54] R. Dhar, "The effect of decision strategy on deciding to defer choice," *J. Behav. Decis. Making*, vol. 9, no. 4, pp. 265–281, Dec. 1996.

[55] P. Costa and R. R. McCrae, *Revised NEO Personality Inventory (NEO-PI-R) and Neo Five-Factor Inventory (NEO-FFI)*. Lutz, FL, USA: Psychological Assessment Resources, 1992.

[56] M. L. Meuter, M. J. Bitner, A. L. Ostrom, and S. W. Brown, "Choosing among alternative service delivery modes: An investigation of customer trial of self-service technologies," *J. Marketing*, vol. 69, no. 2, pp. 61–83, Apr. 2005.

[57] A. C. Raub, *Correlates of Computer Anxiety in College Students*. Philadelphia, PA, USA: Univ. Pennsylvania, 1981.

[58] L. L. Thurstone, "A law of comparative judgment," *Psychol. Rev.*, vol. 34, no. 4, pp. 273–286, 1927.

[59] O. Hinz, C. Schlereth, and W. Zhou, "Fostering the adoption of electric vehicles by providing complementary mobility services: A two-step approach using best–worst scaling and dual response," *J. Bus. Econ.*, vol. 85, no. 8, pp. 921–951, Nov. 2015.

[60] S. Gensler, O. Hinz, B. Skiera, and S. Theysohn, "Willingness-to-pay estimation with choice-based conjoint analysis: Addressing extreme response behavior with individually adapted designs," *Eur. J. Oper. Res.*, vol. 219, no. 2, pp. 368–378, Jun. 2012.

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