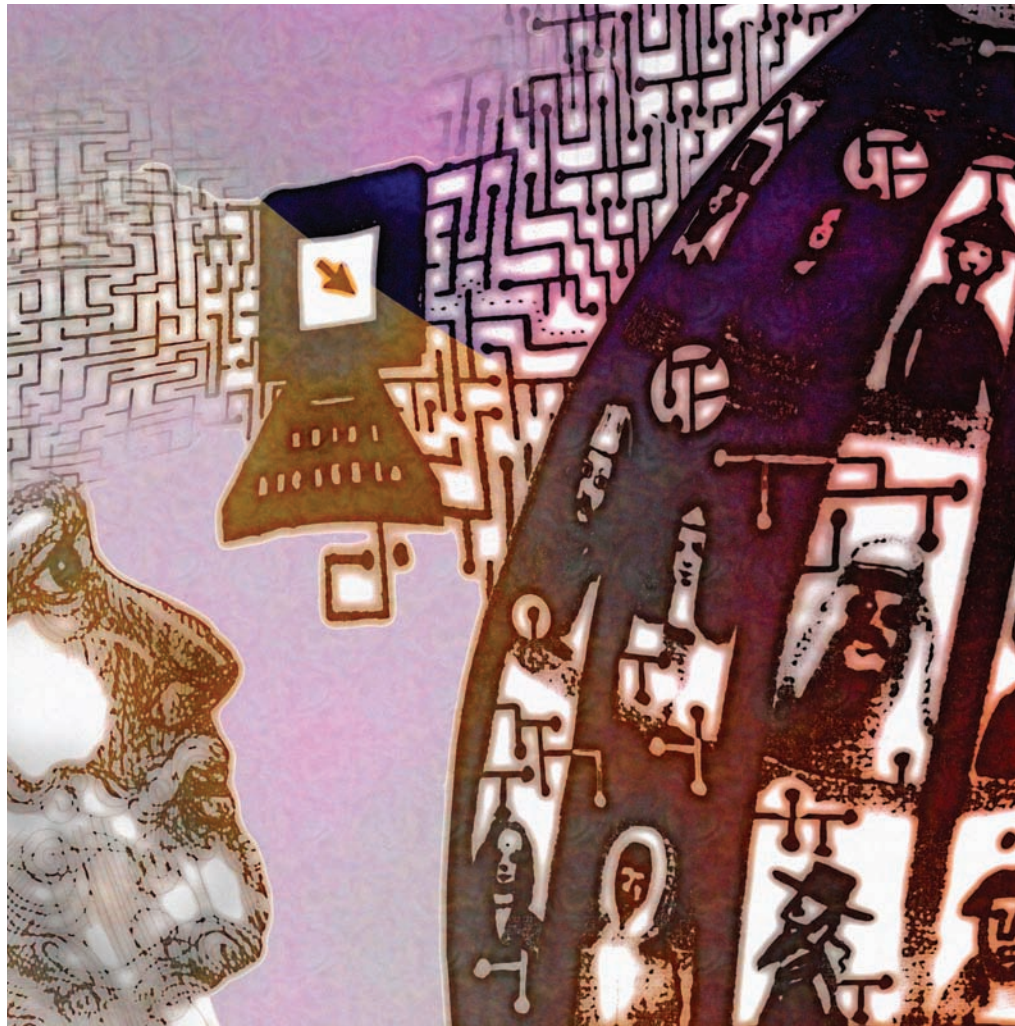


A Novel Dimension of Cooperation in 4G

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The Fourth Generation (4G) of wireless networks is no longer a dream; it is knocking now at the doors of our information village. 4G promises to offer a vast range and diversity of converged devices, services, and networks and to revolutionize the way we communicate. 4G would influence today's networking architecture where the inter-user communication is realized with the help of third-party communication infrastructure. In 4G, the centralized third-party controlled networking architecture can emerge into a hybrid model, where a part of user-to-user interaction would be envisaged by short/medium range wireless communication systems. Moreover, 4G will not only offer ultra-high data-rates but would also enable a ubiquitous computing paradigm, particularly interesting for the end-user with the help of various personalized and user-friendly services. This increase in short-range communication among users and the introduction of such



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personalized services could form a “personal ubiquitous environment” (PUE) around the user. Since in such environments, multiple users will come closer (without any third-party barriers); their cooperation will be the key to the success of 4G.

Importance of Cooperation—Historical Perspective

The development of the modern day computer was the result of technological advancements and the human need to compute. In the beginning of the computing wave when computers were first introduced, they were gigantic and were generally referred to as “mainframes” or as a “central data repository,” linked to users through less powerful devices such as workstations. It was a general belief that these computing devices were specialized machines developed to fulfill specific high computational needs and were of no use for an ordinary user. However, this notion was totally incorrect, and computers proved to be user-friendly and inexpensive, extendable to meeting a large range of user needs. Most dramatic was the emergence of the Internet which glued together so called “personal computers” and introduced a computer culture of cooperation, sharing, openness, and trust. The tradition of cooperation fostered by the Internet and its marriage to personal computers, gave birth to the personal computing paradigm. The personal computing age flourished faster than any other domain, connecting hundreds of millions of people all over the world, making their work available for others on the global information village, i.e., the Internet.

The goal of the original Internet was to provide a unified communication platform for different kinds of devices and networks as well as future technologies, where every single host would be an equal player. However, the fundamental design radically changed with

the emergence of client/server architecture, with a relatively small number of privileged servers serving a huge mass of consumer hosts. This architecture was the opposite of the fundamental design of the Internet, i.e., “a cooperative network of peers.” However, in late 1990s, with the appearance of music-sharing applications such as Napster, the Internet experienced another drastic change, and the architectural design of the Internet reverted to its original “peer-to-peer” notion. The millions of hosts connected to the Internet, inspired by the culture of cooperation and openness, started connecting to each other directly, forming collaborative groups, sharing their resources to become user-created powerful information clusters.

Currently, peer-to-peer applications are using the Internet much as it was originally intended: a common platform for hosts to collaborate and to share information as equal computing peers. In 1908, Nicola Tesla said “The wireless art offers greater possibilities than any invention or discovery heretofore made, and ... we can expect with certitude that in the next few years, wonders will be brought by its applications.” And so, Tesla’s words are true even today. Wireless communication is nothing less than magic for someone who does not know how it works. It enables us to communicate anytime, anywhere (there is a signal), in many forms (data, voice ...). However, wireless technology is not limited to communication; it can offer much more than just a phone call. The limits of wireless communication are still unpredictable and unimagined.

The father of radio communication Heinrich Hertz once said “I do not think that the wireless waves I have discovered will have any practical applications.” The inventor of the first wireless telegraph system Guglielmo Marconi said “Have I done the world good, or have I added a menace?” These early giants of

wireless communications were not sure about the usefulness of their work and were underestimating the power of wireless. They might have envisaged that without the essence of cooperation and sharing, no technology can be economically and socially viable. Cooperation in wireless technologies is the key to discovering a variety of unforeseen innovative applications [1], [2]. This latter aspect is the core reason why cooperation is gradually increasing with increments in the generation of mobile systems, i.e., 1G, 2G, 3G, and now 4G [3]. Today we are at the doorstep of 4G systems, where collaborative services, technologies, environments, and so on, are the major areas of research concern.

Towards Cooperation in 4G

In contrast to what was originally expected, the future is not limited to cellular systems and 4G should not be exclusively understood as a linear extension of 3G [5]. In concrete terms, 4G is more about services than ultra-high-speed broadband wireless connectivity. As predicted in [6], keeping the cellular core, the network architecture in 4G will be predominantly extended to short-range cooperative communication systems. Apart from coverage extension, power and spectral efficiency, increased capacity, and reliability, this enormous flexibility at the user end will help in the development of a personal ubiquitous environment around the user. This environment is indeed the dream of Mark Weiser, the father of ubiquitous computing [1]. The 4G service and technology infrastructure will induce user devices to form cooperative groups and share information and resources in order to attain mutual socio-technical benefits. A whole collection of unforeseen 4G cooperative services will enable 4G technologies to recede into the background of

our lives [1], making us a part of an intelligent and ubiquitous personal substrate.

Until recently, the cooperative services in 4G systems have received significant attention due to their high degree of technological and social flexibility, considerable freedom of choice for the user, and most importantly, the potential mega-revenues for industrial players. In this article, we focus on the services side of cooperation in 4G systems and discuss how these personalized personal/group services will make use of the multitude of wireless systems and networks available under the auspices of 4G.

Futuristic Cooperative Services in 4G

The widely agreed upon rule for success in 4G telecommunication markets is to visualize a cooperative service chain of multiple suppliers satisfying the ever-growing requirements of end customers [9]. The evolution of 4G systems in a multi-dimensional world provided a rich platform for deriving advanced and innovative user-oriented and cooperative services. Embossed to high-level perspectives and equally leveraging on technical dimensions, we recognize several aspects of cooperative services; those related to personal (or group centric) services, intelligent transport network services, cooperative community networks, and large-scale *ad hoc* network services. As shown in Fig. 1, these cooperative and heterogeneous services account for efficient 4G convergence platforms that render clear-cut benefits in terms of bandwidth, coverage, power consumption, and spectrum usage.

The personal and group-centric communication models put forth a multitude of interesting services, benefiting from the “cooperative clouds” formed as a result of multi-level social groups based on self-organizing common objectives [10]. Within this context, various compelling services for smart-home

networking, cooperative healthcare, etc., are shaping up. One such service is the cooperative distribution of media in stationary home networks, where transparency, enabled by a seamless and intelligent platform, equips the home network to become an interdependent service ecosystem for the consumer [11]. Other services in group communication that exploit collaborative behavior include symbolic resource sharing among communication groups (for example, user-centric dynamic content sharing similar to popular web services like MySpace or YouTube), and ubiquitous and collaborative healthcare monitoring at home or hospitals [6]. The Intelligent Transport network is also an interesting setting for providing collaborative 4G services from a user perspective, presented in Fig. 2.

The most interesting among these services is the development of evolutionary cooperative multi-player games as a massive collaborative constellation for vehicular networks [12]. These self-evolving games are targeted at intelligent transport networks that range from private vehicle owners to public transportation system users. Other envisaged services include various location-based services offered on a cooperative basis, where consumers may either locate their intended footage leveraging the collaborative platform, or where they can market their business availing themselves of cooperative advertisement options. This creates an open service ecosystem beneficial for the entire service value chain in vehicular transportation networks [13].

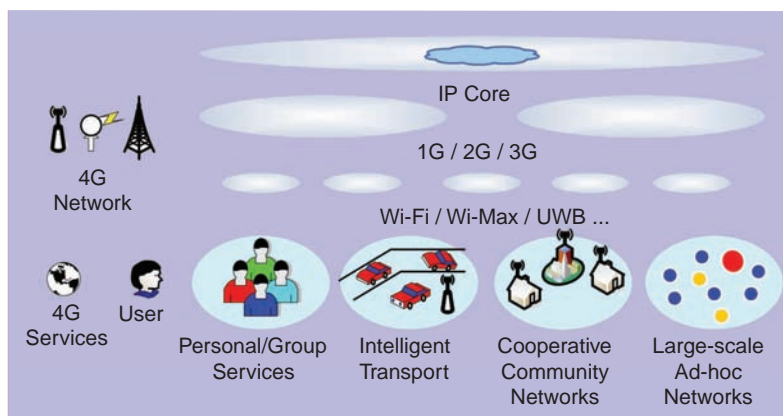


Fig. 1. Cooperation in 4G – services perspective.



Fig. 2. Intelligent Transport Systems (ITS) – A 4G service.

Wireless community networks (commercial, public, and non-profit), as shown in Fig. 3, have matured through the continuing evolution of mesh networks [17], which are now exploiting heterogeneity in a third generation mesh context with the use of multiple radios (including different radios for downlink-uplink), dynamic interference detection and avoidance mechanisms, and automatic location updating mechanisms [14]. Along with the introduction of inter-community networking features this has given new dimensions to collaborative service distribution in community networks. New dimensions include community-based IPTV services, cooperative web-radio, and collective surveillance, etc., apart from common service attributes like resource sharing among users. In general, large-scale user cooperation is an important aspect of the success of community networks triggering the collaborative service-profit chain and introducing competitive differentiation. Mobile *ad hoc* networks applications have made appealing progress, particularly in the field of wireless sensor networks. Many distributed applications are envisaged in sensor networks where collaborative computing [19] assumes

the center stage; smart messaging services for sensors, collaborative objects tracking, etc., to name a few [15].

In the search for niche markets and opportunities for 4G, large organizations and policy makers converge to agree that the 4G landscape will not just be about defining higher data rates or newer air interfaces, but rather will be shaped by the increasing integration and interconnection of heterogeneous systems, with different devices processing information for a variety of purposes, a mix of infrastructures supporting transmission and a multitude of applications working in parallel making the most efficient use of the spectrum [16]. On the contrary, users are getting more varied in the services that they require and the modes with which they prefer to communicate and cooperate, which also hugely influences the future of 4G commercialization. These developments have led us to think along the lines of personal/group services as the most appealing and predominant platform for the development of 4G, where users collaborate in a distributed and cooperative fashion. It is this user-centric cooperation and similar issues that account for the development of cooperative, ubiquitous, personal communication models.

Cooperative Personal/Group Services in 4G Systems

The marriage of the flourishing personal computing paradigm and the networking world, gave birth to a new era of computing called ubiquitous computing [1]. The ubiquitous computing paradigm can also be seen as a byproduct of 4G systems. 4G is not the name of a single technology [7], rather it is a cooperative platform [5], [8] where a large range of heterogeneous wireless networks and services coexist. Under the auspices of 4G, diverse devices, networks, and service elements find their way into the life of the end user. The integration of 4G elements into the end-user environment should ideally go unnoticed to the user, so that the technology eventually focuses on the user rather than the user focusing on the diversity and complexity of the technology around him. It is clear that this preferably invisible and intelligent world of calm 4G technology [1] integrated into the user's world is only possible with cooperation, sharing, openness, and trust within the user's own devices, and among the users that are forming groups. The notion of cooperation in personal/group services may take various dimensions ranging from technology and services to socio-physiological aspects. In order to expand our discussion on the subject of cooperation, we classify into user-centric cooperation and group-centric cooperation. In addition, the cooperation at these magnitudes helps us to move forward towards the development of PUEs [18].

User-Centric Cooperation in 4G

There is a large array of actors in the 4G service arena such as the user, the service/content provider, the network operator, regulatory bodies, researchers and so on, who have stakes in 4G's success. However, economically speaking, the user is a major player, a center of

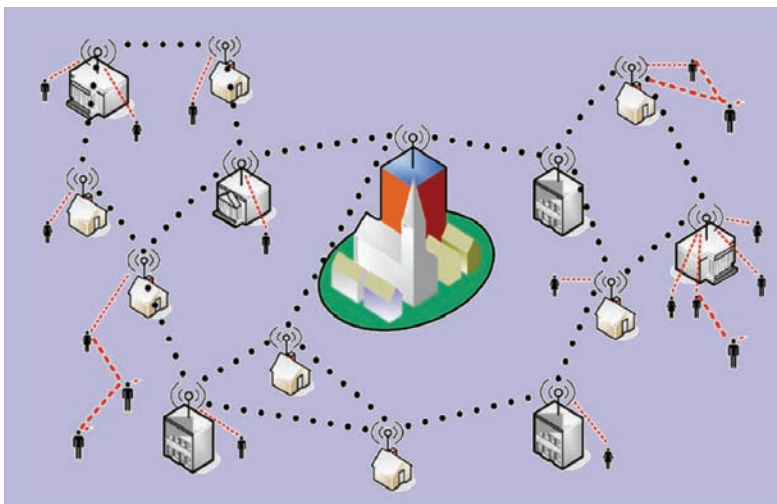


Fig. 3. Cooperative wireless community networks in 4G.

the entire 4G globe, whereas the other actors join hands to meet the expectations of the end user. Taking the technological dimension, in the last few years, a number of heterogeneous devices emerged and networked, ranging from mobile communication equipment to home electronics. This proliferation results in a large range of choices available to the user to communicate in highly diverse environments. As a result, in a 4G system, the user is surrounded by a variety of devices offering a multiplicity of services [21], as shown in Fig. 4. Moreover, the utilization of these devices and services dramatically changes with the change in a user's environment. Therefore, the devices and services in the 4G world should have strong adaptation capabilities.

“Personalization” [3] is a key term here. Since every user is unique in their roles, tastes, and preferences, 4G systems should be intelligent enough to fully understand the user and adapt the network and service elements according to the user's preferences.

In a user-centric model, the user is the focus of the whole system. The cooperation among his heterogeneous devices and his environment is vital for the seamless working of the entire 4G system. Here, we refer to cooperation in two dimensions. At first, the devices themselves need to cooperate, for instance, while the user is busy working on his laptop and he receives an important voice message on his mobile phone, the mobile phone should track the activity of the user in order to notify him about the voice message. To this end, irrespective of their specifications, the user's devices should be able to cooperate in order to help the user in his daily life.

Second, the devices should cooperate with the user's environment. Since user preferences vary with a changing environment, the devices should be capable of dy-

namically adjusting themselves accordingly. For instance, if the user receives a video call while at home sitting in his TV lounge, the mobile phone should intelligently detect the activity/mood of the user and should propose to transfer the video flow on the higher resolution display placed in front of him. Both of these dimensions of cooperation are only possible when the 4G systems encircling the distinct end user fully understand the socio-physiological and the technological potentials and limitations of cooperation.

The personalization aspects of 4G systems are largely similar to the early concept of personal computers (PCs). In the 4G era,

towards personalization and user-centric cooperation, we generalize the concept of PCs and extend it towards personal networks (PNs) [18], first introduced in the EU IST MAGNET project. A PN is a system/network owned and operated by one person, i.e., the PN owner. The PN owner is the sole authority in his personal interconnected devices and can use the PN in the way he wants. The personal devices may be located, both in his close vicinity and at remote locations. Fig. 5 presents the PN of Bob, which is composed of his home, office, and car clusters. The owner of the PN can add new devices or personalized services

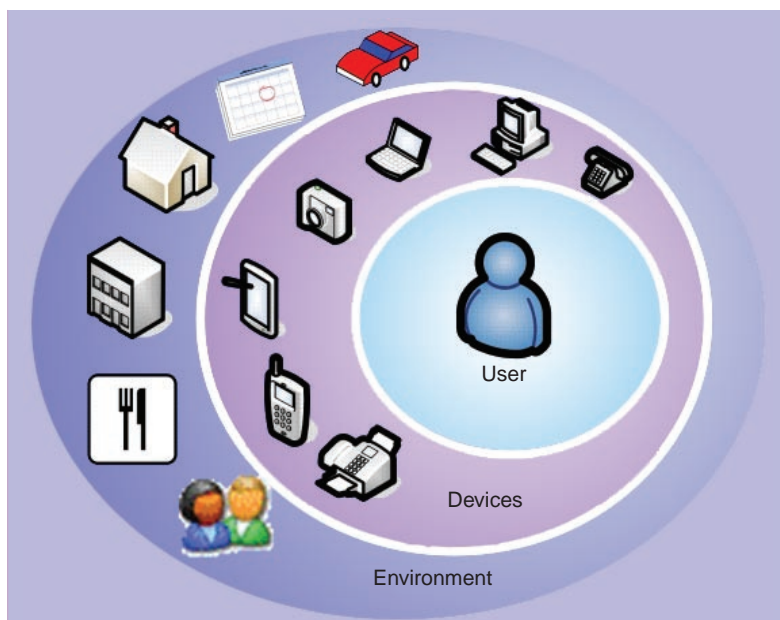


Fig. 4. User-centric cooperation.

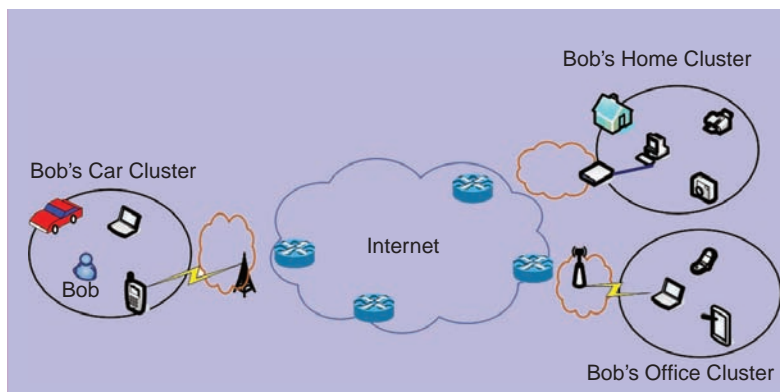


Fig. 5. Bob's personal network.

to their personal network at will. For its owner, the PN is a heaven of personalized services in cyberspace. But to the outside world, it appears as a black box.

Group-Centric Cooperation in 4G

Human nature does not promote “living in isolation.” The emergence of communication networks is alone proof of it. Group-centric cooperation is also referred to as cooperation among the end users who are organized in groups. This is in many ways fundamentally opposite to user-centric cooperation, where only the user’s devices and environments cooperate, and their cooperation appears as a dark cloud to the outside world (to other users). In fact, the 4G services that can be made available to a single user (with user-centric cooperation) are limited, and users need to cooperate with each other to extend their global services repository. In addition, many service-oriented patterns need to extend the boundaries of “user-centric cooperation” and involve the secure interaction of multiple users having common interests for various professional and private services.

In order to promote group-centric cooperation in 4G systems, the concept of personal network federations (PN-F) [22] has been recently introduced in the EU IST MAGNET Beyond project (Phase II of the MAGNET project). PN-Fs address the interactions between multiple PN users with common interests for a range of diverse services. A PN federation can be defined as a secure impromptu, situation-aware or beforehand-agreed cooperation between a subset of relevant devices belonging to different PNs for the purpose of achieving a common goal or service by forming an efficient collaboration.

Consider the PN-F B in Fig. 6: a simple example of PN-F is the federation of PNs belonging to a group of students in a classroom, sharing lecture notes.

Based on how the cooperation between devices in different PNs is realized in order to establish the federation, we can differentiate between infrastructure and spontaneous PN federations [22]. In an infrastructure-based federation, a PN-F is established between devices in PN clusters that are all connected to an in-

frastructure network. As shown in Fig. 6, the infrastructure PN-F, i.e., PN-F A, is formed between user 1 and user 2, who are located across the infrastructure network. On the other hand, in a spontaneous, *ad-hoc* PN-F, the federation is formed in the absence of a fixed infrastructure. This type of federation mostly occurs when nearby users collaborate within a federation. PN-F B in Fig. 6 presents a spontaneous PN-F formed among user 3, 4, and 5.

Towards Personal Ubiquitous Environments in 4G Systems

As discussed in the previous sections, both user-centric and group-centric cooperation are required in order to meet the long-term expectations of a 4G-enabled ubiquitous computing world. Cooperation among the users, their devices, and their environments results in the development of a personal ubiquitous environment around the user, which permits “ubiquitous global access” to a vast number and variety of information resources [18], [20]. This uniform and comprehensive sense of cooperation results into a vast base of services for all the users who are the part of this PUE village. In the language of personal networking, we collectively define PN (personal network) and PN-F (PN federation) as a personal ubiquitous environment (PUE).

As shown in Fig. 7, three users join hands to share devices, services, and environments to form a cooperative group (PUE /PN-F). In PUE space, the users believe in the essence of openness and sharing not only for their self-centric goals but also for the global benefits of the entire cooperative community. Those users, who are satisfied with their own proper resources and do not have any intention of cooperating, stay in their own user-centric environments, i.e., PN, as highlighted in Fig. 7.

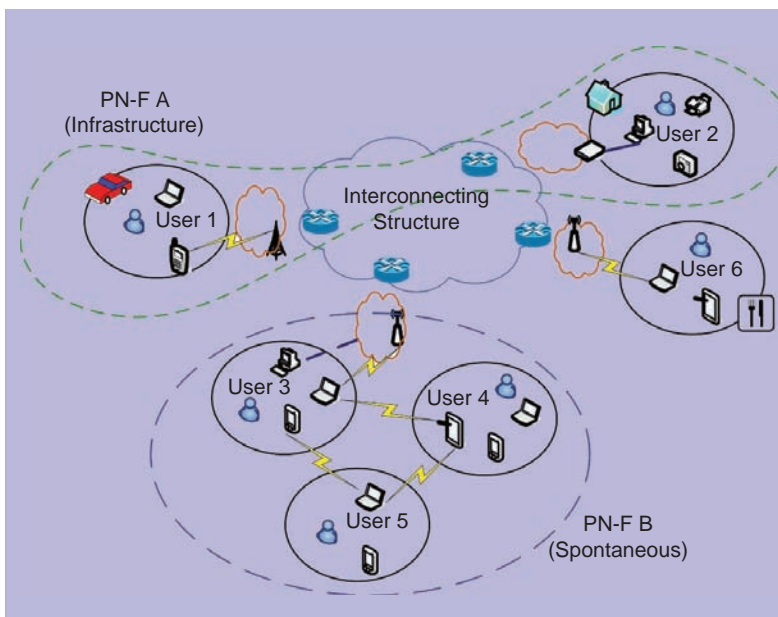


Fig. 6. Personal network federation architectures.

Socio-Technical Dimensions – Potentials and Limits of Cooperation

Socio-technical dimensions may either limit or support cooperation in 4G collaborative services. We focus on the PUE as one of the foremost services arena in 4G. The PUE is particularly interesting in terms of social implications of cooperation because the user in a PUE is totally free to cooperate within his own network and with others, without going through certain rigid sets of obligations from the service provider or the network operator (which is the case in cellular/infrastructure-based networks today). In PUEs, we consider a scenario in which a group of users are located within each other's spatial proximity and are open to cooperate and share services and applications. However, some basic questions may arise here. For example, why does the user want to extend his PUE in order to accommodate other users, what is he interested in and more importantly, what would he be able to get after forming the PN-F with other users, and finally, what price might the user have to pay for these services. We base our discussion around three fundamental stances outlined in the following three sub-sections.

Before the Cooperation Begins

The PUE of a user first constitutes his own devices and services available in his PN. The user is the sole authority to extend his PUE (to form a PN-F) in order to accommodate the services and the devices available to other users in their own PNs. However, before really moving towards cooperating and forming groups, the user first looks at his motivation to cooperate. Adam Smith, the father of modern economics said, "Every man, as long as he does not violate the laws of justice, is left perfectly free to pursue his own interest his own way." In terms of cooperative

groups, if the user feels satisfied with the services he has in his own PN, no desire to cooperate and to form groups will arise. The user shall only devise ways into cooperation when he looks for some service that his own PN (or current PUE) cannot offer. The user's intent to cooperate can be classified in several ways: purpose-driven cooperation vs. opportunity-driven cooperation, short-lived cooperation vs. longer-term cooperation, and proactive cooperation vs. reactive cooperation.

Purpose-driven cooperation means that the cooperative strategies are explicitly defined beforehand, whereas opportunity-driven means that the users cooperate spontaneously when interesting circumstances to do so arise. In both cases, and especially in the second, information about the user's context/environment/activities can play an important role. Next, depending on the lifetime of the cooperative groups, we can make the distinction between very *short-lived* cooperation and *longer-term* cooperation. This distinction will have its implications on the complexity of the solutions to establish the cooperative groups. In the case

of short-lived cooperative groups, solutions to set up and manage the cooperation need to be lightweight and simple. Longer term cooperation opens up many more opportunities to introduce more complex and powerful management and definition mechanisms. Finally, based on the way the cooperation process is carried out, both *proactive* and *reactive* cooperative groups are possible. Proactive implies that the cooperative groups are established in anticipation of the use of the common goals or services provided by the cooperation strategies of each group user. Last but not the least, reactive cooperative groups are established upon request or when the opportunity arises.

Formation of Cooperative Groups

In precise terms, a cooperative group is a function of cooperation strategies defined by each participant of the group. First the group members define their local strategies and exchange them with the other members. The exchange of strategies is similar to negotiation between the end-users, i.e., what each of the users wants to provide and consume as a part of the

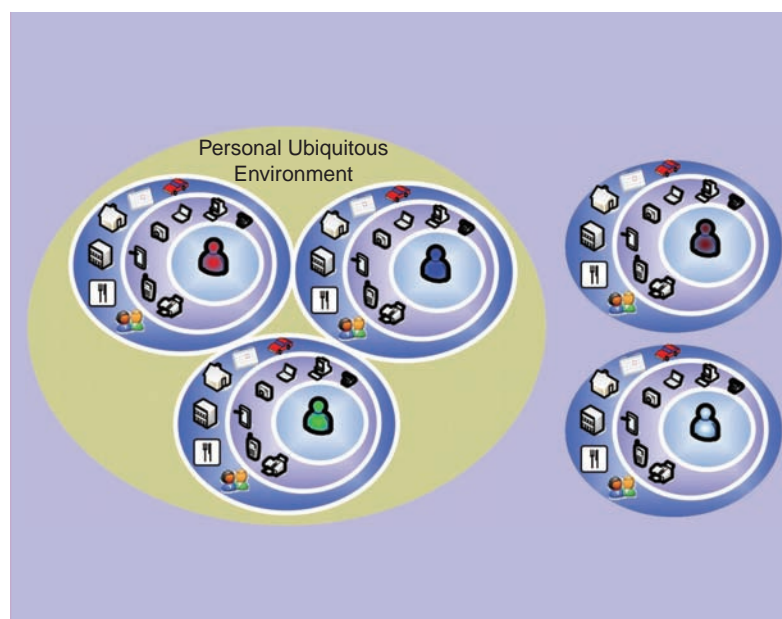


Fig. 7. Some personal networks interact; some do not.

A cooperative group can have multiple convergence points.

cooperative group. For instance, as shown in Fig. 8, there are three distinct PNs who want to form a cooperative group (a PN Federation). Before forming the group, they negotiate on the terms and conditions of the PN-F. As an outcome of this negotiation, all of the potential cooperative group (PN-F) members converge at a certain point (a group

of strategies), referred to in Fig. 8 as the “convergence” point. Once the convergence point is attained, i.e., the common strategies for the cooperative groups are defined, then the cooperative groups are actually formed.

Cooperative groups may vary on different scales such as age, profession, likes, needs, culture, and so on. Thus, it is less likely at times that they converge on a single point. The derivation of common strategies for the entire group gets more complicated and any increase in the number of members of the cooperative group. Moreover, even if the members finally converge to certain agreed upon strategies of the group, the time it would take to form a group would be considerable. Therefore, it may be quite efficient that certain group members converge on some strategies and do not converge on others. Or it is also possible that the cooperative group defines one single strategy as a “general” strategy for the group, and other “specific” strategies for cooperation among group members.

To this end, a cooperative group can have multiple convergence points. As in Fig. 9, PN-1 defines two disjointed convergence points with each of the other PNs (i.e., PN-2 and PN-3) in the group. In concrete service terms, in the scenario considered in Fig. 9, the cooperative group is formed by the PN-1 to consume/provide service to each of the other PNs, whereas other PNs, i.e., PN-2 and PN-3 might not be interested in each other’s services. Therefore, in order for the group to achieve its goal, the convergence points of PN-1 with other PNs are essential. However, in this case, a more complex problem is to provide a secure and efficient interface between each of the convergence points defined within the scope of the cooperative groups. Moreover, during the lifetime of the cooperative group, due to the dynamism of

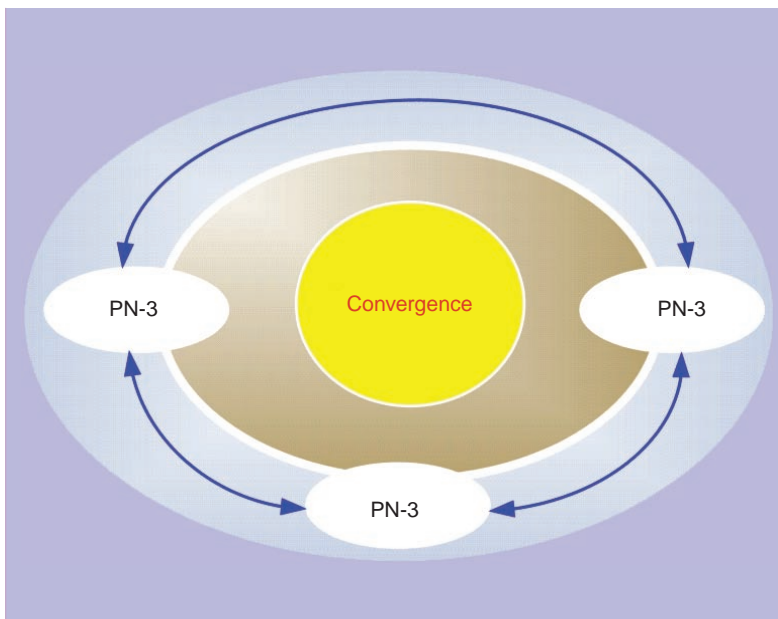


Fig. 8. Cooperation among PNs.

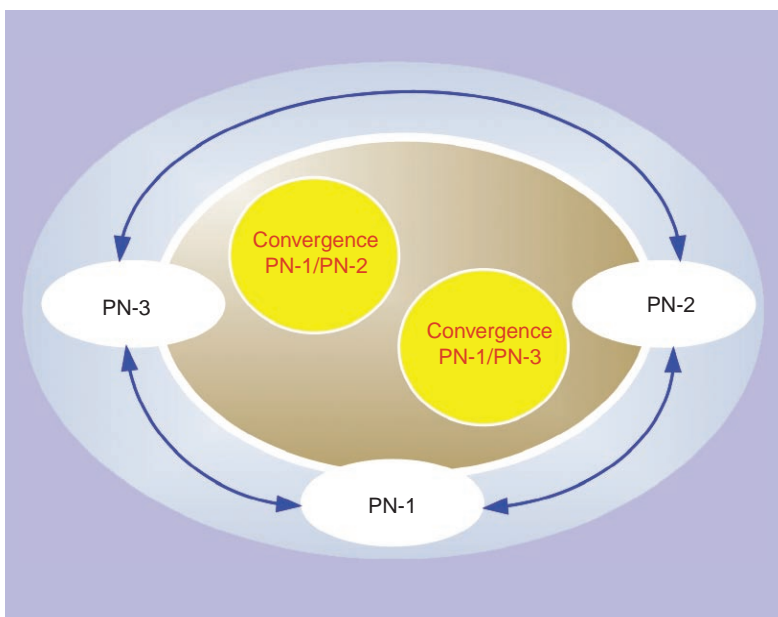


Fig. 9. Cooperation among PNs.

the group and its members, individual strategies can change. Coping with this dynamism in cooperative group environments is also a hard nut to crack.

Sharing Strategies in Cooperative Groups

In order to fully understand the sharing strategies in cooperative groups, it is interesting to observe how the economics of cooperation work in society in general. Cooperation refers to the practice of people or greater entities working in common with commonly agreed upon goals and possibly methods, instead of working separately in competition [23]. In society, we cooperate when we want to accomplish something that we can not achieve working alone. In contrast, sometimes we cooperate not for obvious short-term benefits but for long-term gains. For instance, User A relays the traffic of User B so that in future, User B would be in a position to ask User A to relay his traffic. This type of cooperation involves business, cultural, and relationship development aspects. Whatsoever the reason behind the cooperative behaviors is, cooperation does not come for free and we always have to pay a certain price for it. The cost and the gains of cooperation can take many forms ranging from resources (man, money, machines) to moral and ethical support, referred as the potentials of cooperation.

Even if all members of a group benefit from the cooperative group, individual self-interest may not favor cooperation. This theory of non-cooperative behavior for self-interest in a cooperative group is referred as “prisoner’s dilemma” [25]. There can be several reasons to be non-cooperative in a group. One of the major reasons is associated with the utility of being the part of the group. Everyone wants to have the best thing under the cost constraints he has. Therefore, the

We cooperate when we want to accomplish something that we can not achieve working alone.

user would be cooperative to a certain limit where his total utility of being cooperative is greater or equal to the cost he is paying as a part of the cooperative group. Since the total utility and related cost are associated with the satisfaction of the user, once the cost bypasses the total utility the user’s satisfaction starts decreasing, and he becomes more egoistic, or a less cooperative member of the group.

In this section, we discuss the potentials and limits of cooperation by applying Nash Equilibrium (NE) theory (part of game theory) to PUE concepts. John Nash introduced the concept of Nash equilibrium in his doctorate thesis and showed for the first time in his dissertation, *Non-cooperative games* (1950), that Nash equilibria must exist for all finite games with any number of players [24]. In PUE, where different PNs join hands to form a cooperative group (PN-F) in order to share certain services, let (S, f) be a cooperative group, where S is the set of strategy profiles and f is the set of payoff profiles. Let σ_{-i} be a strategy profile of all group members except for member i . When each member of the group $i \in \{1..n\}$ chooses strategy x_i resulting in strategy profile $x = (x_1, \dots, x_n)$ then member i obtains payoff $f_i(x)$. Note that the payoff depends on the strategy profile chosen, i.e., on the strategy chosen by member i as well as the strategies chosen by all the other members. A strategy profile $x^* \in S$ is a Nash equilibrium if no unilateral deviation in strategy by any single member is profitable, that is, if for all i ,

$$f_i(x^*_i, x^*_{-i}) \geq f_i(x^*_{-i}, x^*_i). \quad (1)$$

In descriptive terms, if there is a set of group strategies with the property that no group member can benefit by changing his strategy while the other members keep their strategies unchanged, then that set of agreed-upon group strategies and their corresponding payoffs constitute the Nash Equilibrium in the cooperative group. Therefore, in a Nash Equilibrium none of the group members can unilaterally change his strategy to increase his payoff.

We have analyzed the potentials and limits of cooperation with the help of NE theory under multiple group members (PNs) scenarios, who form a Personal Network Federation (cooperative group). Moreover, contradicting the basic NE concept, we have also studied the scenarios where multiple equilibrium points are possible. In our study, the cooperative group strategies model referred to as “consume/provide” is based on basic supply/demand economics theory [26].

Potentials of Cooperation in 4G’s Personal Ubiquitous Environments

The potentials of cooperation in PUEs are associated with the strategic satisfaction of each cooperative group member. This implies that the percentages of his local strategies are reflected in the common group strategy. As discussed earlier, towards the formation of cooperative groups (PN-F), each group member (PN) prepares his proper local strategy and then exchanges it with the other potential group members. A group member who first initiates the group formation process is referred as a group

The derivation of common strategies for the entire group gets more complicated with any increase in the number of members of the cooperative group.

creator (PN-F creator). In concrete terms, a local strategy contains the information related to the participation of the member such as which services he wants to consume/provide, what are his preferences (security, quality of service

(QoS), economic, etc.) for certain services, how much time is he willing to remain a member of the cooperative group, and so on.

After an exhaustive exchange of local strategies among the cooperative group members, a final group

strategy is prepared. This strategy is the convergence point in the entire cooperative group space. If all the group members agreed on a certain group strategy to the extent that none of the group members wants to unilaterally change his strategy to increase his payoff, we can say that the cooperative group has attained a Nash Equilibrium point as shown in Fig. 10. The X-axis in Fig. 10 represents the “consume” strategy, whereas the “provide” strategy is on the Y-axis. Here, three members (PNs) join hands to form a cooperative group (PN-F). PN-1 is the creator of the cooperative group. After some negotiation of their own local consume/provide willingness, they all agree on a certain point, which is marked in Fig. 10(a) as the “Equilibrium” point. Fig. 10(b) highlights a much different behavior of PN-1 (creator) in the cooperative group. Since PN-1 is the initiator of the group, it is quite possible that he might be more open to provide as much service as possible to the group with comparatively very limited desired to consume services. This behavior is much justifiable in the society, as a manager or the front-liner is normally the center of focus of a group and his behavior has a strong impact on the strategies of the other group members. Therefore, for the success of a group, the initial strategy defined by the mentor of the group is highly important.

It is important to note that the Nash Equilibrium point presents the minimum set of “provide” strategies owned by all the cooperative group members. It is of course possible that, at the later stage of cooperation, one of the members may express a generous attitude and provide more services by keeping his “consume” strategy constant, as can be the case with PN-1 in Fig. 10(b). To this end, the equilibrium point will shift keeping the entire group’s “consume” strategies constant. This phenomenon of moving an equilibrium point with a variable “provide”

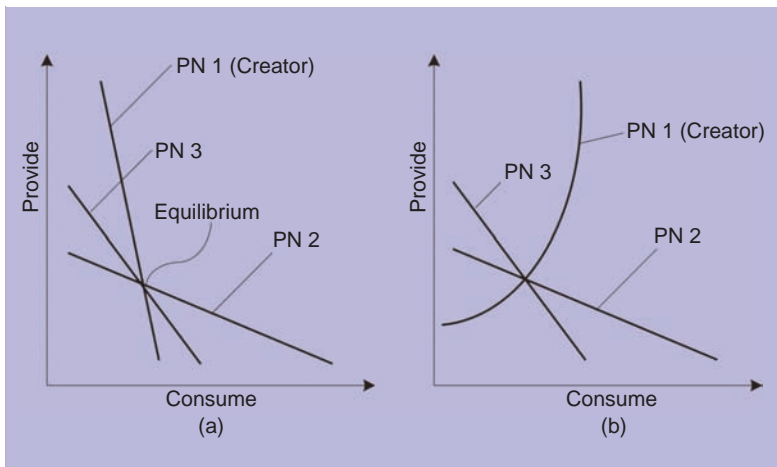


Fig. 10. (a) (b) Potentials of cooperation in PUE – Consumer/provider strategies.

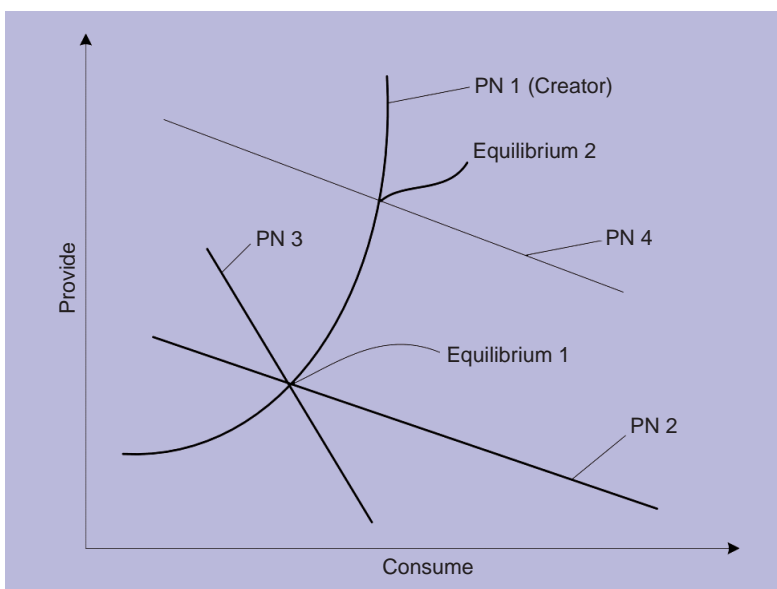


Fig. 11. Potentials of cooperation in PUE – Multiple equilibrium strategies.

strategy of one member, and “constant” consume strategies of all the other members, can be clearly studied on a three-dimensional graph, where the *X*-axis is “consume” strategy, the *Y*-axis is “provide strategy, and *Z*-axis is “equilibrium.”

As we normally see in society, some players in a group have their own proper stakes associated with only certain members or certain goals of the group. They stay with the group only for such limited benefits as a part of the entire cooperative group’s ecosystem. To this end, a group may have multiple equilibrium points satisfying all group members as a whole or some of them. As shown in Fig. 11, a group consists of four members such as PN-1, PN-2, PN-3, and PN-4. Lets assume that PN-4’s interest in the group is only associated with some services offered by PN-1 and he is not interested in any other service. In this respect, as in Fig. 11, we have two equilibrium points such as Equilibrium-1 among all members except PN-4 and Equilibrium-2 between PN-1 and PN-4. In multiple equilibrium group cases, it is important that both the equilibrium strategies should have a certain level of interface among them. As in the example in Fig. 11, a strong communication between both strategic equilibrium points would monitor and control the accurate working of the group. For example, here in this example, this interface ensures that PN-4 only consumes the services of PN-1 as defined by Equilibrium-2 and does not interact with any other group services made available by other members in the group.

Limits of Cooperation in 4G’s Personal Ubiquitous Environments

Sometimes certain group members either cooperate in a way that their cooperation is not useful for the group or they behave in a totally non-cooperative way (becoming egoistic). Both of these situations

Cooperation does not come for free and we always have to pay a certain price for it.

limit cooperation in the PUE. The former case is discussed in Fig. 12(a). A cooperative group has three potential members such as PN-1, PN-2, and PN-3. The strategies defined by PN-1 and PN-2 cause them to settle down to a certain equilibrium point, whereas PN-3 is not party to the common equilibrium. In Fig. 12(a), the strategy of PN-3 is represented by a straight line parallel to the *Y*-axis (provide). This implies that for PN-3, while he is a very cooperative member of the group, his cooperation is not interesting for the other group members. For example, PN-3 is providing services that are not needed by the other members. In this case, an ideal equilibrium point among all the group members is blocked by the local strategies of PN-3.

The latter case, where some members become egoistic, is discussed in Fig. 12(b). In Fig. 12(b), again three PNs are potential cooperative group members. Here we clearly see that PN-2 and PN-3 are extremely egoistic in their cooperative behaviors, i.e., they are inclined towards consuming much more service than offering to other group members. This case is again

a bottleneck in the formation of a cooperative group with certain essential equilibrium point(s).

One way to overcome this bottleneck in cooperative groups is to reward more for cooperative attitude and to punish more for a non-cooperative attitude. In the absence of any reward/punish mechanism, the non-cooperative behavior will have a tit-for-tat effect on the entire group. For instance, if a cooperative member’s partner defects from cooperative behavior, the group responds in a similar non-cooperative way towards other partners. This chronic behavior will rapidly spread within the group, and it might end with a total non-cooperative group, where no member is willing to cooperate.

Vision of the Future for 4G Systems

In the Hollywood film “A Beautiful Mind,” John Nash said that “Adam Smith said the best result comes from everyone in the group doing what’s best for himself, right? Adam Smith was wrong! The message: Sometimes it is better to cooperate.” Cooperation is the buzz word in the communications industry today driving the

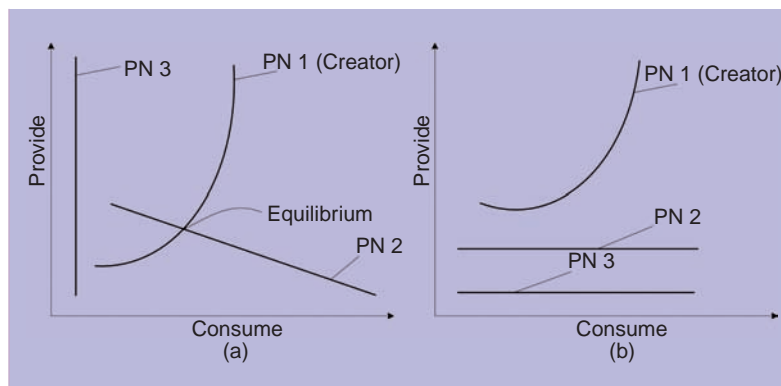


Fig. 12. (a) (b) Limits of cooperation in PUE – Egoist/ineffective cooperation.

notion of cooperative mechanisms in future heterogeneous systems, including 4G. The 4G landscape is so diverse, and the industry leaders and strategic leaders accept that 4G is not only about improved data rates or diverse air interfaces and unified standards, but rather is going to be shaped by increasing integration, collaboration, and interconnection of heterogeneous systems. On the contrary. The widely agreed upon rule for success in 4G telecommunication markets is to visualize a cooperative service chain of multiple suppliers satisfying the ever-growing requirements of end customers. This intertwined and inspiring direction could facilitate the realization of a large scale cooperative and of ubiquitous wireless communities.

Furthermore, for personal or group communication environments particularly, PUEs could eventually be forerunners for exploiting the theoretical limits of cooperative systems, enabling the provision of niche cooperative systems and services. This potential capability needs to be explored in much detail, understanding socio-technical aspects and potential limits of cooperation, and developing efficient models to develop and nurture cooperative societies. Several socio-economic aspects need to carefully observed and studied, such as human factors with respect to human nature, ego-centric human behaviors, and social factors such as the effects on society, economic competition, etc.

From a service perspective, we believe that the future of cooperative services in 4G largely depends on the result of cooperation of major players in industry including service providers and vendors, etc., on one hand and policy makers, academia, etc., on the other. From a technology perspective, our opinion is that the large-scale integration of coexisting applications and incorporation of emerging technologies, flexible models for spectrum allocation,

etc., should be considered in depth. Finally, encouraging healthy interworking between application research and technology research, and supporting seamless cooperation should be the vision of the future of 4G systems.

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