Exploiting Cooperation for Performance Enhancement and High Data Rates

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***Abstract*— In this paper, we discuss an approach to increase wireless bandwidth utilization based on cooperative network architecture, referred to as Cellular Controlled Peer-to-Peer (CCP2P) communication. This approach goes beyond the concepts used in composite networks, focused mainly on coverage extension and data relaying. In CCP2P networks, besides being connected to an "outside world" using cellular links, a group of terminals in close proximity form a cooperative cluster. Using peer-to-peer connections CCP2P has the potential to overcome many important limitations of the cellular networks and offer higher data rates and better Quality of Service. Four practically relevant scenarios of CCP2P applications are presented as illustrative examples and discussed in detail. This paper shows that performance gain can be achieved only by cooperative behavior of terminals in the cluster. The importance of rules of cooperation for CCP2P communication is underlined and a discussion on their realization in cooperative networks is provided.**

***Index Terms*— cooperation, network architecture, bandwidth utilization, efficiency**

I. INTRODUCTION

In recent years, we have witnessed increasing demands for high bandwidth, low-delays and reliability dictated by end-to-end services [1]. Multimedia applications, applications based on computer clustering and storage networking, and Internet-based applications put forward these demands. At the same time, cost and efficiency of information delivery is another important factor. To achieve end-to-end gigabit rates, bottlenecks in high-speed networks should be completely eliminated or at least minimized. However wireless connections are still presenting a challenge for high data rate information delivery.

To translate performance improvements on physical data rates over wireless into corresponding improvements at the application level, an efficient wireless bandwidth utilization is required. Here by efficient utilization we understand the increase in the amount of time bandwidth is used for the actual data transmission and the reduction of overhead that can be in the form of long packet headers and data retransmissions due to packet errors. In practice this can be achieved by e.g. applying compression and coding techniques, using multi-path streaming and advanced error/ loss recovery methods. Additionally, efficient utilization of multicast and broadcast information is required. In this paper our focus is on different approaches on how to increase the bandwidth utilization of wireless links and thus make the end-to-end application with high data rate requirements the reality. All the presented approaches have one thing in common: they exploit the advantages of peer-to-peer computing combined with the advantages of a centralized overlay network.

Network architectures exploiting peer-to-peer connectivity form a basis for distributed computing. Peer-to-peer systems consist of nodes that are able to interact with each other and self-organize into network topologies with the purpose of sharing resources such as content, CPU cycles, storage and bandwidth. Prominent application areas of these systems include distributed and scalable computing, database systems, Internet service support, content distribution, communication and collaboration [2].

Peer-to-peer wireless networks, known also as ad hoc networks, have been intensively studied over the last decade. Their self-organization capabilities and independence of infrastructure make this kind of networks attractive for diverse applications, in home and office environments as well as in military and disaster relief operations.

Following a different approach, cellular networks are based on a centralized architecture: a terminal always communicates though an access point and direct interactions between terminals are not allowed. Thus, services are provided to a given terminal only via the access point. The quality of the received service will highly depend on the available (but limited) system capacity. Cellular networks are known to suffer from the scalability problem: for a given number of users n, the fair throughput per user decreases as $O(\frac{1}{n})$. Additional factors limiting the type and quality of service (QoS) that can be wirelessly delivered are the physical and regulatory limitations in energy and power usage in terminals and access points respectively.

Recently, alternative network architectures have been proposed aiming at improving the performance of cellular data networks. These basically consider hybrid architectures where both the centralized (e.g., cellular) and distributed (e.g., peer-to-peer) topologies are combined. A great

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Manuscript received September 8, 2008; accepted December 11, 2008. Corresponding author Tatiana K. Madsen.

deal of these *hybrid* or *composite* networks are proposed for coverage extension purposes, by using ad hoc relays and multi–hop techniques. For a comprehensive review of these networks readers are refereed to [3]. Interesting applications of cellular-ad hoc composite networks are for instance opportunity driven multiple access (ODMA) [4], where the problem of data rate degradation toward the cell boundary is addressed by traffic relaying through terminals within the high-bit-rate coverage area; and integrated cellular and ad hoc relay (iCAR) systems [5], where traffic load balancing between cells is achieved by relaying traffic from an overloaded cell to the neighboring cells. A somewhat different approach has been proposed in [6]: a hybrid system architecture enables high-quality games among multiple wireless users. During a game the data exchange is done over short-range connections, whereas the authentication and score reporting is conducted over the cellular network.

Discussions on feasibility of ad hoc technologies for future IP based wireless and cellular networks can be found in [7]. Additionally, as shown in [3], performance improvement using ad hoc relaying can be expected only in situations when sources and destinations are collocated within the same cell. In cellular data environments, terminals use the access to the base station primarily for service acquisition, e.g., e-mail access or video download. In other words, the main portion of traffic comes from up- and downloading to and from servers in the Internet, respectively. Therefore, these ad hoc relaying based approaches can only solve the scalability problem of cellular networks to a limited extent. In general the hybrid or composite networks considered so far combine the mentioned networks in a rather *static* fashion, that is, the cellular network is augmented or complemented by the ad hoc network but the active interaction between the networks is not significant.

In this paper, we present a *dynamic* approach to bridge cellular and peer-to-peer architectures, referred to as *Cellular Controlled Peer-to-peer communication* (CCP2PC) [8], [9]. Besides being able to communicate with the base station using cellular interfaces, terminals have the capability to establish direct peer-to-peer connections over short-range links. A group of terminals, typically in close proximity, form a cooperative cluster that is a peer-to-peer network in its full right. The base station works as a service entry point and administrator for instance for authentication and billing purposes. Peer-to-peer connections can be potentially used for content distribution, error healing and retransmissions. The envisioned scenarios for CCP2PC include partial distribution (or full distribution with selective reception) of information over cellular links and its recombination using peer-to-peer connections. The approach considered here dynamically utilize the available resources (e.g., time, frequency), aiming at exploiting simultaneously the advantages of both network topologies. Indeed, CCP2P has the potential to overcome many important limitations of the cellular networks. The synergy (both in the static and dynamic sense) between the two involved networks can be exploited by creating a common pool of resources. This is what makes an integration of wireless heterogeneous networks attractive.

It has always been understood that performance of cooperative and peer-to-peer networks depends on the level of cooperation of the participants. The common pool of resources can be created only by cooperative interactions among users. While most existing peer-to-peer networks are built on the assumption that participants are generally cooperative, there is a growing evidence suggesting the opposite. The problem of how to effectively engage a selfish rational user to contribute with his own resources to the common pool is still an open issue. The basic dilemma of cooperation consists in the following: cooperative nodes in principle bring benefits to the entire network, but, in some scenarios, particular nodes acting selfishly can reduce or even eliminate the benefits of cooperation. Staring from [10], there have been many contributions addressing this problem. The proposed mechanisms include trusted third parties, usage of reputation information or application of reciprocal punishment. To design a successful cooperative network, the rules of user behavior should be better understood.

In summary, the contributions of this paper are the following:

- We present a composite network architecture that combines centralized cellular and distributed peer-to-peer network models. The advantages of the peer-to-peer information redistribution in a cellular network are demonstrated in four different scenarios. The considered scenarios include unicast and multicast transport, as well as unicast and multicast services.

The rest of the paper is organized as follows. Section 2 presents a way to combine peer-to-peer networks with cellular data networks. In Section 3, we advocate this architecture by providing four scenarios where the cooperative strategies lead to better Quality of Service, higher robustness and lower power consumption. Scenarios include an IP header compression algorithm, a retransmission scheme, IP-services over DVB-H and digital content downloading in disjoint parts. In Section 4, strategy for cooperation in wireless communication systems is discussed. Finally, Section 5 provides concluding remarks.

II. CELLULAR CONTROLLED PEER-TO-PEER COMMUNICATION

The problem of cooperation in wireless networks can be approached from different angles. In [8], [11] a classification of levels of cooperation is given. It distinguishes *implicit* and *explicit* cooperation. In implicit cooperation, the interaction takes place without any preestablished cooperative framework. If cooperative behavior is supported by network design, this approach is referred to as explicit. The next level of cooperation includes *macro cooperation*, where the collaborative entities are macroscopic parts of a wireless system, and *micro cooperation*, where the cooperation is performed on the level of functional parts

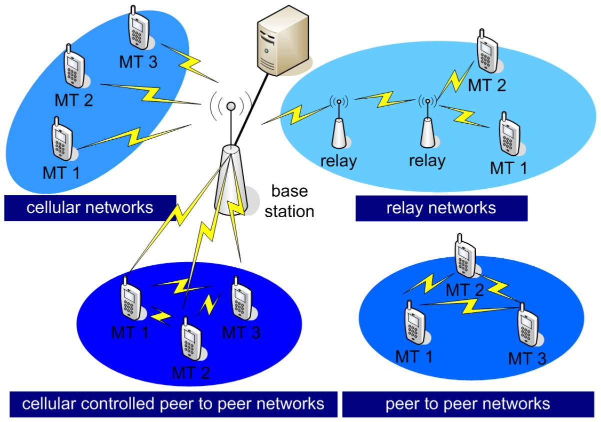

Figure 1. Four network architectures: cellular networks, relay networks, peer-to-peer networks, cellular controlled peer-to-peer networks.

(e.g., particular functional blocks, algorithms, etc.) Cooperation in peer-to-peer networks corresponds to micro cooperation, where independent terminals contribute with e.g., processing power or bandwidth. The goal of this paper is to demonstrate the advantages of using micro cooperation in designing of future generation of wireless networks.

Bits transmitted over the radio channel use the always scarce wireless bandwidth and depletes batteries of mobile terminals. Considering the limited bandwidth resources and the current status of battery technology, efficient bandwidth utilization and reduction of energy consumption are goals of many optimization schemes or novel network architecture design [8]. These goals can be potentially achieved by using the micro cooperation concept.

There are two conceptually opposite approaches in architectural design of wireless networks: centralized and distributed. The former one is represented by cellular networks: wireless terminals are connected to the AP that plays a role of a controlling entity, as well as an entry point to acquire services. Peer-to-peer networks correspond to the distributed approach: direct communication among users facilitates information exchange. Currently, the cellular data networks are represented by GPRS (2G) and UMTS (3G) standards. The achievable data rate over GPRS or UMTS is limited, and what is more, it degrades as the number of active users in a cell increases. A typical scenario that is used to illustrate the scalability problem of a cellular network is the ”stadium”: a big crowd of people is gathered in one place, e.g., stadium to watch a popular event. A particular situation (e.g., a scored goal) is likely to trigger many people to use their mobile phones. Due to high temporal correlation of the requested services, the network will rapidly be overloaded and eventually collapse. To solve this problem, load balancing can be performed by forwarding the requests and serving a subgroup of the users through neighboring cells (”forced” handover). Depending on the geographical location of the neighboring access points and their current traffic load, up to a certain amount of users can be served. To facilitate traffic load balancing between the cells, special relays (mobile or fixed) can be deployed. Alternatively, mobile terminals can play the role of relays. In any case, using relay stations data is sent through multiple hops. The approach advocated in this paper is to use cellular controlled peer-to-peer networking. In the considered example, the service content requested by the users can be expected to be correlated. Instead of sending in parallel the same content to all users, the data can be transmitted only to a sub-group. Afterwards, the terminals that have received the content will forward it to the rest of the users using peer-to-peer connections. Figure 1 illustrates the four network architectures discussed above.

If wireless terminals have the capability to communicate with an AP and simultaneously with other terminals (by using either the same or different air interfaces), then a peer-to-peer network can be established. By using short-range links, cooperative groups can be formed[1]. We refer to the network architecture formed in this way as cellular-controlled P2P networks. It has been noted that using short-range links for data transmission is less costly compared with the cellular links since higher data rates and lower powers for transmission and reception can be achieved over close distances [8]. As communication over the short-range links use unlicensed spectrum, a better utilization of this expensive resource is also attained. Additional benefit of using micro cooperation in cellular systems comes from multi–path diversity: if a radio path between an AP and a terminal is greatly deteriorated by the instantaneous channel conditions, a data packet is lost. A neighboring user might be experiencing good channel conditions and might be able to distribute the content to the whole group of terminals. Cooperative techniques can virtually allow low bit error rates in typically stringent wireless channels without employing heavy error protection coding and less efficient but more robust modulation schemes.

One should note that in CCP2P networks a controlling entity (an access point) should be aware about the cooperation among terminals. If the terminals are using the same air interface to communicate with the AP and for short-range connections, then activity alternates between the cellular and short-range communication links and the AP should allocate time for inter-terminal information exchange. Additionally, taking into account information distribution using peer-to-peer connections, there might be a need for content adjustment made by the AP.

To illustrate the application areas of CCP2P, we consider two types of services, unicast and multicast, and two types of data delivery, unicast and multicast transmissions. The service is said to be unicast (multicast) if data is delivered from a source to a single user (to a group with an arbitrary number of users). By multicast transport we understand a mechanism where data packets destined for multiple recipients are sent over a channel only once. Opposed to multiple transport, unicast connections are

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[1] Short-range connections can be realized in practice by using Bluetooth or WLAN technologies.

Scenario 1 Unicast service Unicast transport E.g., IP Header compression	**Scenario 3** Unicast service Multicast transport E.g., IP services over DVB-H
Scenario 2 Multicast service Unicast transport E.g., Bittorent	**Scenario 4** Multicast service Multicast transport E.g., Retransmission scheme

TABLE I.
FOUR CONSIDERED WIRELESS SCENARIOS EXPLOITING THE CCP2P CONCEPT

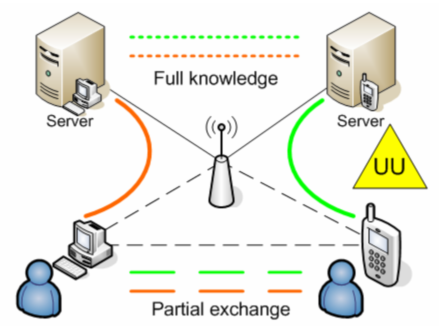


Figure 2. Scenario 1

those where each packet is sent over a channel once per user.

A scenario matrix is given in Table I (see also Fig. 2-Fig. 5). Scenario 1 presents delivery of a unicast data service over cellular unicast links. IP header compression is applied for transport overhead reduction. Partial exchange of information using peer-to-peer cooperative network translates into high robustness and bandwidth utilization of the compression scheme. Multicast service with unicast transport data delivery is given in Scenario 2. Employing micro cooperation, data is partially distributed over cellular links to the members of a cooperative group and recombined by using peer-to-peer connections. This method allows achievement of virtually high data rates. Delivery over multicast cellular channel is considered in Scenarios 3 and 4. Scenario 3 demonstrates that high bandwidth and energy efficiency can be achieved by using selective reception of information over cellular link. In the last scenario full distribution of information is performed over cellular links with selective partial exchange using short-range communication. It leads indeed to power savings. Next section presents a detailed description of each scenario.

III. SCENARIOS FOR COOPERATION: A CLOSER VIEW

In this section we discuss in detail the cooperative scenarios considered in Table I and Figure 2.

*A. Cooperative IP header compression (*Unicast service, Unicast transport*)*

Considering unicast services over unicast transport channels, we give an example of cooperative IP header compression [12]. Header compression techniques can be applied to reduce the overhead introduced by IP/UDP/RTP protocol encapsulation. The reduction of header size is especially important for bandwidth-limited links, such as cellular links, since it can virtually increase the achievable data rates. However, high bit error rates of the wireless environment are detrimental to the IP header compression. This is in fact the well-known problem of error-propagation [13]. By compressing headers, the redundancies between contiguous packets of a given flow are removed by using differential encoding. Random fields of packet headers are transmitted unchanged, whereas delta fields are compressed by reference to

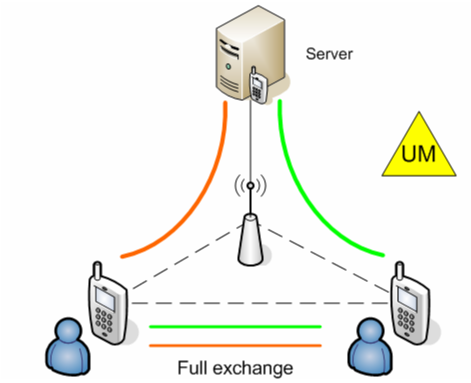


Figure 3. Scenario 2

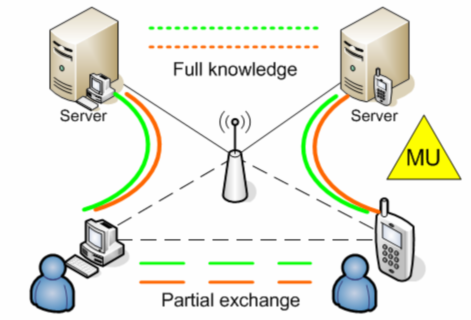


Figure 4. Scenario 3

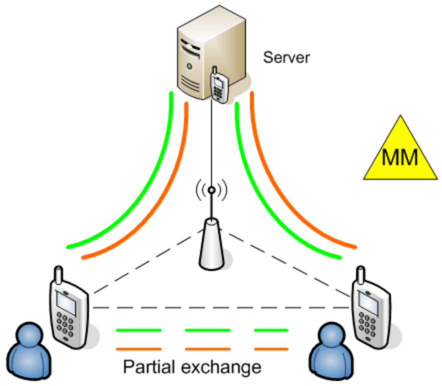


Figure 5. Scenario 4

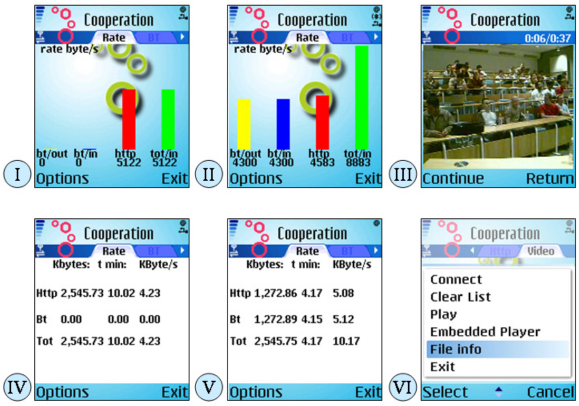
the previous packets, also called context. The context is known and maintained at the receiver side as well and used for decompression of the incoming packets. The context is updated with every new packet. Packet losses lead to inconsistencies in the context state at the decompressor and failure of the decompression procedure. This lead to the appearance of an error burst. Typically, an application layer can deal with single errors, but loosing multiple packets in a row means significant degradation of QoS perceived by the user.

To avoid bursty errors, we propose to use terminal cooperation to stabilize IP communication. A peer-to-peer network formed by terminals can provide "first aid" information to heal the decompressor state of the neighboring node in case of packet loss on the cellular link. Since the terminals within a cooperative group receive different data streams, each of the terminals should receive some extra information from the AP destined to the neighboring users. It will typically mean two bytes more per packet [12]. Even though the size of a compressed header is slightly increased in the cooperative case compared with a conventional non-cooperative header compression scheme, the overall bandwidth efficiency using peer-to-peer help exchange is higher. Fig. 6 shows the average bandwidth saving for cooperative header compression (assuming two and three terminals in the group) and for non-cooperative approach. The graphs are plotted versus responsiveness of the network towards channel errors measured in packets. The better performance of the system exploiting cooperative behavior can be explained by its error healing capabilities. Thanks to peer-to-peer information exchange, the decompressor will stay operational for a long time without need for the context update. One should note that it is exactly the request for the update sent by a terminal to the AP and the full context update sent by the AP that drain the system resources (bandwidth and battery power).

The presented header compression scheme exploits multipath diversity effect. Therefore, in the considered scenario the assumption of uncorrelated errors on channels between the AP and the terminals is essential in order to obtain performance gain. If the terminals experience correlated channel errors, that is, the packet losses on different channel are correlated in time, cooperation should be stopped. Additionally, if a user experiences favorable channel conditions, the best strategy for him is not to join a group. Indeed, under low packet loss rate the need for the full context update is rare, and a user does not need help from the neighboring terminals. This statement is confirmed by Fig. 7.

B. *Dowloading of digital content (*Multicast service, unicast transport*)*

Downloading of digital contents is a representative example of multicast service over unicast transport channels. We assume that a server hosts a digital content, which can be accessed by mobile terminals using the cellular air interface. If they are further able to cooperate with each other over the short range link, the server offers the possibility to download disjoint parts of the digital content, which will be merged later over the cooperative short-range links. In order to validate the discussed principles, a cooperative application for Symbian based mobile phones was implemented. Two commercial terminals (Nokia N70 phones) were employed in the trial to illustrate the practicality of the concept. Both terminals, within proximity of each other (in our test the distance between the terminals was approx. 2 m), use the BitTorrent file sharing approach. Both users are assumed to download the same file at the same time. The terminals use the Bluetooth module of the phones to communicate with each other and a GPRS connection to the base station. Using the GPRS link the terminals can reach a predefined server in the IP backbone. The IP server provides two download possibilities namely full file (standalone download) and split-file version, with two equally large files. In the standalone download, each terminal downloads the full version in a given time T, with a data rate R, spending an energy E. In the cooperative download, obviously the download time is nearly halved, thus T/2. The not so obvious benefit is the reduction of the energy consumed by 44%. The reason for this behavior lies in the lower energy per bit ratio of Bluetooth than GPRS. In Figure 8, screenshots of the application show the rates for the server (HTTP), the incoming and outgoing Bluetooth connection, and the total incoming data rate while the cooperative download is ongoing. This data rate is referred to as virtual rate as it does not come directly from the base station, but is nonetheless usable for the application. This example shows how higher data rates (without substantially increasing complexity) and lower energy consumption (with an improved quality of service) can be achieved through cooperation.



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bt/out bt/in  http  tot/in
0      0      5122  5122
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bt/out bt/in  http  tot/in
4300   4300   4583  8883
```

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     Kbytes:  t min:  KByte/s

Http 2,545.73 10.02 4.23

Bt   0.00     0.00  0.00

Tot  2,545.73 10.02 4.23
```

```
     Kbytes:  t min:  KByte/s

Http 1,272.86 4.17  5.08

Bt   1,272.89 4.15  5.12

Tot  2,545.75 4.17  10.17
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Figure 8. Screenshots of the cooperative download application.

C. *IP-services over DVB-H (*Unicast service, multicast transport*)*

The representative example considered here is of IP services that are transmitted with the Parallel Elementary

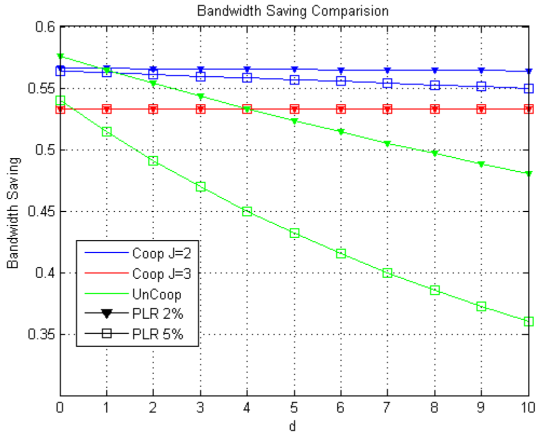

Figure 6. Bandwidth saving vs network responsiveness. Packet Loss Rate= 2%, 5%.

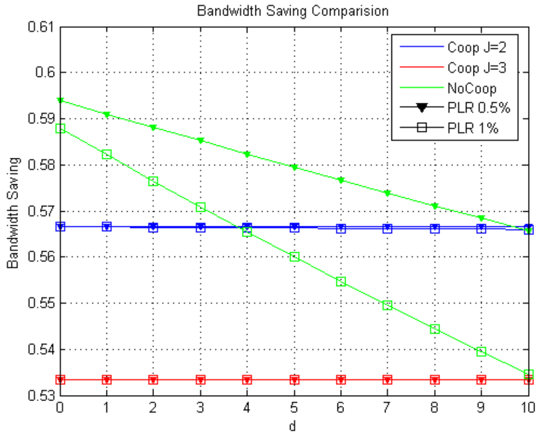

Figure 7. Bandwidth saving vs network responsiveness. Packet Loss Rate= 0.5%, 1%.

Stream technique in DVB-H networks. First two concepts need to be introduced: time slicing and parallel elementary steam. Time slicing is employed in DVB-H to save power [14]. The idea of time slicing is to convey data in bursts with long pause periods in between instead of sending a steady low data rate stream. The power consumption with time slicing depends on the burst duration and the so called OFF-time period. There are constraints of burst duration and OFF-time in DVB-H networks. The burst duration must have minimum length to relax the sensitivity requirements of the receiver. OFF-time can not be too long due to quality of service aspects such as the access time and zapping time[2]. Therefore, there is clearly a trade-off between burst duration and OFF-time to have optimum service access time and power consumption.

IP-services over DVB-H can be transmitted in sequential elementary streams (SESs) or parallel elementary streams (PESs) [14]. Both types of streams are transmitted in a multicast or broadcast fashion. The SESs carry one service in one burst, while PESs carry multi services in one burst. The reason that multi services are bundled and transported within the same burst is that the burst needs to meet a minimum length requirement while the DVB-H system tries to get the maximal utilization of the DVB-H bandwidth. The use of parallel elementary streams brings many benefits, for instance, zapping time reduction, bandwidth optimization, the possibility of sending message type services in parallel to the main services, etc. However, when mobile terminal receives its target IP service carried by PES during one burst, it receives also other services in the same burst block. In the state–of–the–art, mobile terminal simply keeps the desired elementary stream and discards the remaining ones. From the entire system or network standpoint, the elementary streams discarded by a given terminal could be used by other mobile terminals. So in this scenario although terminals have individual interested services (”unicast” service), they can still cooperatively receive the DVB-H bursts. Each cooperative node only needs to receive partially the data over DVB-H link. Then the node does not discard the unwanted packets anymore, but forwards those packets to its cooperative peers over the short range link. By reciprocity, it gets its missed packets from those peers. Thus mobile terminals virtually increase the OFF-time and reduce the average power consumption. Fig. 9 shows that mobile terminal can attain 54% power saving gain when it cooperates equally with other two nodes. (Theoretically it can get 66% power saving but the short range link also costs it some power consumption.) Note that this cooperative strategy does not require any modification in current DVB-H standard. The short range link communication is easily implemented in the mobile terminals.

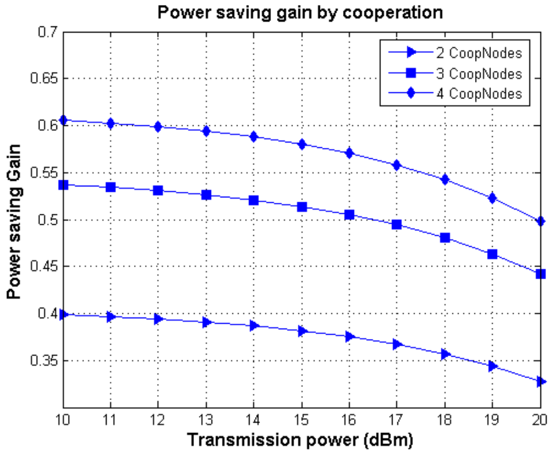

Figure 9. Power saving gain by Cooperation

In this cooperative example, the delay of pay off is one burst cycle period, about 2-3 seconds. So it can also be regarded as instantaneous reciprocity. It is very easy to detect a cheater. Because in order not to miss the burst the mobile terminal always uses *hello* message to check

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[2] Zapping time means the program or channel switching time.

if its partners are still in its proximity before each burst starts. If one node attempts to cheat and does not reply the *hello* message, its partner will regard it unavailable and stop cooperating right away.

*D. Cooperative retransmission scheme (*Multicast service, multicast transport*)*

A good case in point for multicast service by multicast transport is the cooperative retransmission scheme for reliable multicast services in wireless networks. The assumed scenario is that the multicast server connects with Base Station (or Access Point) and multicasts data over cellular link (CL). Many data dissemination applications such as software distribution, data distribution and replication and mailing list delivery, etc. [15] require reliable multicast. Traditional error/loss recovery schemes such as pure ARQ, pure FEC or hybrid ARQ are not efficient when they are applied to multicast scenarios in wireless networks. The reason lies in the unreliable and heterogeneous wireless channel, the battery powered wireless terminals, the limited wireless bandwidth, and others. For instance, pure ARQ has scalability issues such as implosion and exposure [16]; and pure FEC can not provide full reliability [17]. Performance of HARQ degrades significantly for heterogeneous channels conditions, which was proven in [17]. The idea of cooperative retransmission is that the wireless terminals in the same multicast group can form a cooperative cluster if they are close to each other. Most of the losses/errors can be recovered by local retransmission within the cooperative cluster over the short–range link. A novel cooperative retransmission protocol using a logical ring based mesh topology is considered here. It means that the retransmission duty is assigned to the node according to the logical ring topology. But the node uses mesh topology to multicast the requested packets within the cluster when the node does its retransmission duty. It essentially reduces the average number of transmissions required to receive a packet reliably at all the receivers over the CL. Consequently it improves CL bandwidth utilization. It can also reduce retransmission delay due to the higher data rate, shorter distance between transmitter and receiver and higher reliability of the short–range link. One would be concerned on the additional energy consumption in the terminal resulting from the overhead on the short–range link. However, fortunately, the energy overhead on the short–range link is very low due to the energy per bit is much lower on the short–range than in the cellular link. Fig. 10 and Fig. 11 give the energy consumption comparison of different loss/error recovery schemes. Fig. 10 shows that the cooperative retransmission scheme outperforms ARQ and Layered FEC, furthermore it has comparable performance as HARQ under homogeneous channel conditions. Fig. 11 illustrates the advantage of the cooperative retransmission scheme under heterogeneous channel condition. It can be seen that cooperative retransmission scheme has better performance and attains 40% energy saving gain compared with HARQ when there are 128 nodes in the multicast group and 5% nodes with bad channel condition (20% packet loss rate) and the rest of nodes with 5% packet loss rate.

The design of the cooperative retransmission protocol highly follows the rules of cooperation. First it meets the timely reciprocity requirements. The average delay of the benefit feedback in the proposed cooperative protocol is only at the order of seconds, which can be regarded as nearly instantaneous reciprocity. Second, the node's position in the logical ring topology is ordered according to the node's contribution to the cluster (i.e., the number of packets that the node has sent). It can effectively avoid free riders. Last but not least, the nodes can tolerate the delay of pay off when a small fraction of nodes have higher packet loss. The nodes with good channel condition will help the others to recover the packet loss/error in the cooperative cluster due to the multicast group membership. But the tolerance is on the condition that the nodes with higher packet loss have done their best to do contribution for the cooperative retransmission.

IV. DISCUSSION ON THE COOPERATION STRATEGY IN THE CONSIDERED SCENARIOS

In this section we discuss on the possible cooperative strategies in the four considered scenarios, highlighting. The underlying principles of cooperative behavior observed in nature can be summarized by the following five rules: i) reciprocal behavior; ii) detection of cheaters; iii) pay-off should be received within a pay off cycle; iv) tolerance to the pay-off delay depends on membership relation of the involved group members; and v) detection and cognition of group members. A vast amount of research has been conducted aiming at encouraging cooperation in peer-to-peer and wireless ad hoc networks. The typical way to approach this problem is by introducing an accountability mechanism (or a system of credits) on top of trust to facilitate cooperation. Accountability should provide guarantees for reciprocal behavior and avoid "free riders". However, compared with the conventional peer-to-peer networks, CCP2P should also cope with problems that arise due to unpredictable behavior of wireless channel and heterogeneous packet loss rates experienced by terminals.

It is a challenging task to ensure reciprocity and, at the same time, to detect and punish (isolate) cheaters in networks with a large population. It is not feasible for terminals to keep track of all other counterparts which have had interactions with them previously. The memory requirements to account for the cooperation status with all users can be prohibitively high. Additionally, due to the large scale of the system, repeated interactions with the same user are not likely to occur in such highly populated scenarios. In the presented scenarios for CCP2P cooperation, any user possessing a mobile device can potentially act as cooperating entity, that is, a cooperative group can be formed among any users of two billion mobile phones. One can argue that the probability to interact with terminals belonging to the people from your

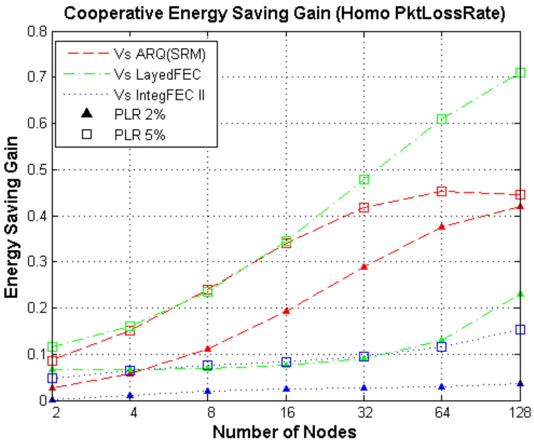

Figure 10. Energy saving gain of Cooperation Scheme (homogeneous Packet Loss Rate).

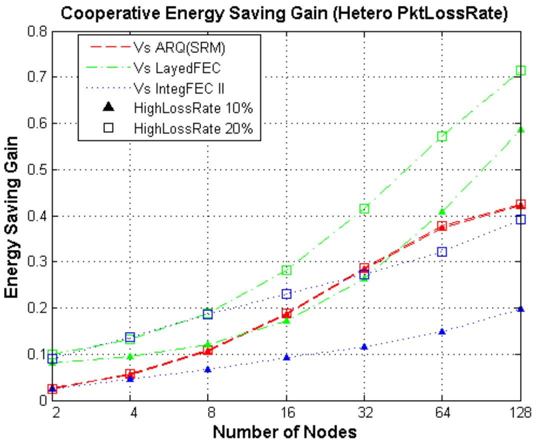

Figure 11. Energy saving gain of Cooperation Scheme (heterogeneous Packet Loss Rate).

address book is much higher compared with a probability to form a cluster with a total stranger from another part of the world. Indeed, clustering with trusted partners is easier from the point of view of cooperation strategy complexity and in many cases it is a much desired situation. However, in the general situation the lack of history, (or in other words zero-knowledge initial state) should be assumed.

Performance evaluation of the considered scenarios for micro-cooperation in CCP2P networks has shown that the gain from cooperative behavior is typically maximized for clusters with a small number of terminals. In Scenarios 1 and 4 a group consisting of two or three terminals seems to be optimal [12]. Then high robustness of the compression (Scenario 1) or fast error recovery (Scenario 4) can be achieved. In Scenario 3 more terminals result in higher power savings, but using e.g. Bluetooth technology for short-range connectivity the number of devices in a group should not exceed 8 (the number of devices in one piconet). Generally, the optimal number of cooperating terminals will depend on the particular technology that is chosen to support peer-to-peer networking and parameters associated with cellular link data transport (such as loss rate, delay etc). However, varying values for different parameters, in our simulations the best performance has been observed for groups of size from 2 to 8 terminals [19]. Increasing the number of terminals further, the performance gain from cooperative behavior is dropping due to the overhead introduced by short-range communication.

Considering the limited number of terminals in cooperative groups, the task of guaranteeing reciprocity is greatly simplified. This can be achieved by a simple tit-for-tat strategy: individuals store the result of the last interaction made by those they interact with and return the same if they meet again in the future. In practice, the tit-for-tat strategy can be realized with a counter-based algorithm involving threshold values. When forming a cooperative group, each user assigns a threshold value (payoff margin) for all other members of the group. The threshold represents the delay that the user can tolerate in receiving a pay-off in the pay-off cycle. Each user maintains a table that records information on previous interactions with other terminals and contains current status of a transaction history. The current payoff value $Payoff_{i,j}$ can be calculated as follows:

$$Payoff_{i,j} = Reward_{j,i} - Cost_{i,j} + \sigma \qquad (1)$$

where σ is a payoff margin, $Reward_{j,i}$ is the service provided to the jth user and $Cost_{i,j}$ is the service received from the jth user. The payoff margin and service are measured in the number of data packets (Scenarios 2, 3 and 4) and the number of context updates (Scenario 1) received over the short-range link. The $Payoff$ value is updated after each interaction. If $Payoff_{ij} < 0$, then terminal i stops providing service to the terminal j.

Lets consider now how reciprocity can be ensured in a wireless environment. We can define reciprocity as

$$Reciprocity = \frac{S_i \times N}{S_T}$$

where S_i is the service provided by the ith user, S_T is the total amount of service exchanged in the group and N is the group size. $Reciprocity = 1$ means absolute reciprocity: a user receives the same amount of service he is providing. $Reciprocity < 1$ corresponds to the case when the user receives more service than what he contributes. $Reciprocity > 1$ means that a user contributes more than what he receives. Let us consider Scenario 1 with two terminals forming a group for cooperative context state exchange. Figures 12 and 13 show reciprocity versus life time of a cooperative group for homogeneous case (the average packet loss rate experiencing by the both users is the same, 1%) and heterogeneous case (average packet loss rate is 1% for one user and 3% for another user). Both figures are plotted assuming infinity payoff margin. In the first case we observe a convergence to absolute reciprocity. The second case reflects unfairness between users: one provides more service.

The unfairness problem observed in Fig. 13 can be mitigated by applying payoff margin as suggested by (1).

If the current value of the payoff counter becomes negative, a user stops providing service to the corresponding terminal in the group and waits until he will be provided with the service. A user experiencing high packet loss rate exhausts the limit quickly, and many of his requests will remain unanswered even though his partner is capable to fulfill the requests. Considering i.d.d. packet losses with 1% and 3% loss rates, on average two thirds of the requests of the second user are not served. This degrades overall system performance. However, as it is shown on Figures 14 and 15, reciprocity can be guaranteed. The payoff margin is set to be 5 in Fig. 14 and 50 in Fig. 15. Smaller values for payoff margin means faster convergence to the absolute reciprocity. Additionally, as it is shown in [18], if the threshold value is chosen small, by frequently joining and leaving the group, a cheater will not receive much benefit.

When designing algorithms for cooperation among wireless devices, additional issues should be taken into account. Indeed, a terminal might not have the requested content to share with other terminals in a group due to the high bit error rates caused by the wireless channel as well as unreliable transmission. Thus, this terminal can be mistakenly assumed to be a cheater. Lets consider Scenarios 1 and 4. A terminal will request a context update or a broadcasted packet from a neighboring terminal only in case it has experienced a packet loss. A request will not be fulfilled in two cases:

- another terminal is a cheater;
- channel errors experienced by two terminals are correlated in time.

In both cases cooperation should be stopped. Therefore, the tit-for-tat strategy can be applied without need for any changes.

We should distinguish between a selfish node and a cheater. A selfish node will not cooperate if it does not bring any benefit for him, thus he might choose not to provide any service to others and not to request any service for himself. A cheater tries to acquire services from others without providing service in return. It is not a crime to be practical. We can expect that an egoistic user will join a cooperative group only if needed, e.g., when experiencing bad channel conditions and consequently high packet loss rates (cooperating he can virtually reduce packet loss rate), or when the terminal is a hand-held device with limited battery capacity (cooperation will increase his operating time). Considering a limited lifetime of a cooperative group, the best strategy for a terminal with a lot of resources is not to join a group. This will degrade the total performance of a group. To overcome this problem, more complicated schemes can be employed that virtually prolongs pay-off cycle. Using a centralized approach, an AP can play a role of a trusted authority. The record of cooperative interactions is stored at the centralized entity and forming new group the terminals does not start from zero-knowledge state, but use their previous records. If in a decentralized approach a separate status value is kept for each pair of terminals, now it is substituted with one global variable. A well-placed terminal might be willing to help other terminals in a group in order to score points for his future usage. Other schemes can be developed, e.g., when the amount of scored points affects billing: a ”helpful” user can get a fee reduction by the network operator. However, we should note that virtually prolonging the pay-off cycle comes by the price of significant overhead for maintenance of a shared history and additional signalling for interactions report.

As the last point, we would like to mention that the cooperative behavior is dependent on the presence and actions of other terminals in the vicinity. Device discovery and intelligent clustering based on the available device functionalities is essential for efficient cooperation. Here we come to the fifth rule, detection and cognition of group members, that is by itself a vast research topic.

V. CONCLUSIONS

In this paper we have discussed a composite architecture as well as an associated cooperative framework aiming at enhancing performance and improving the efficiency in the use of resources. The approach brings into a closer and dynamic relationship cellular and peer-to-peer networks. To achieve cooperation among cellular terminals, a peer-to-peer network is formed using the short-range connectivity capabilities of the terminals. As in any kind of peer-to-peer network, in the considered composite network, synergy and thus, performance gain, depends on the willingness of the peers to cooperate. We have presented and discussed four different scenarios where cooperation among terminals in CCP2P networks leads to improvement in Quality of Service, robustness, delay, bandwidth utilization or power consumption. It has been showed that a limited number of terminals in a co-operative cluster (e.g., from two to eight) guarantees high performance gain while the complexity of the cooperative strategies remains low. The rich and dynamic cooperation is the considered composite architecture offers a lot of potential to improve key performance measures of wireless networks and still remains as a largely unexplored area for research.

REFERENCES

[1] S. Zeadally, L. Zhang. Enabling Gigabit Network Access to End Users. Proceedings of the IEEE, Vol. 92, No.2, February 2004.

[2] S. Androutsellis-Theotokis, D. Spinellis. A Survey of Peer-to-peer Content Distribution technologies. ACM Computing Surveys, Vol.36, No.4, pp. 335-371, December 2004.

[3] H.-Y. Hsieh, R. Sivakumar. On Using Peer-to-Peer Communication in Cellular Wireless Data Networks, IEEE Trans. on Mobile Computing, Vol.3, No.1, pp. 57-72, January-March 2004.

[4] 3GPP, ”3GPP TSG-RAN; Opportunity Driven Multiple Access”, TR 25.924, V1.0.0, December 1999.

[5] H. Wu, C. Qiao, S. De and O. Tonguz, Integrated Cellular and Ad Hoc Relaying Systems: iCAR, IEEE J. Selected Areas in Comm. (JSAC), Vol.19, No.10, pp. 2105-2115, Oct. 2001.

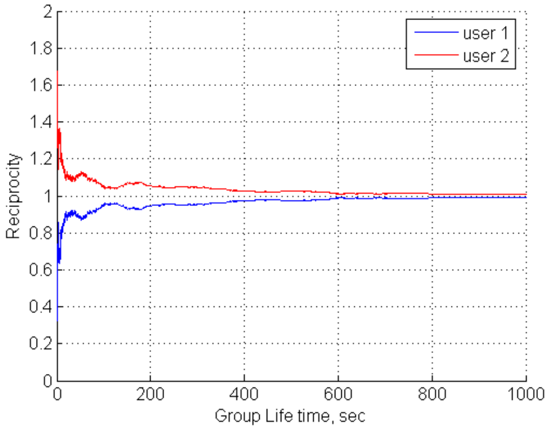

Figure 12. Reciprocity vs group life time. Packet Loss Rate = 1%.

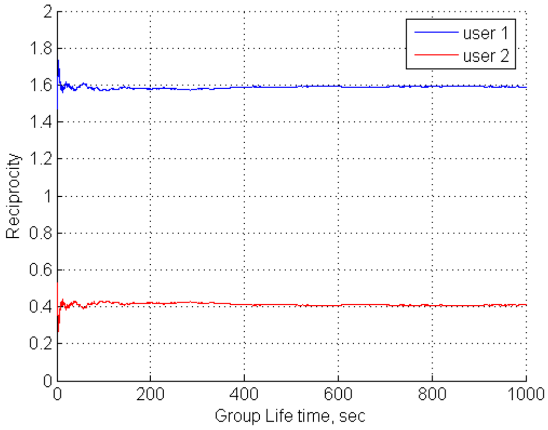

Figure 13. Reciprocity vs group life time. Packet Loss Rate = 1% and 3%.

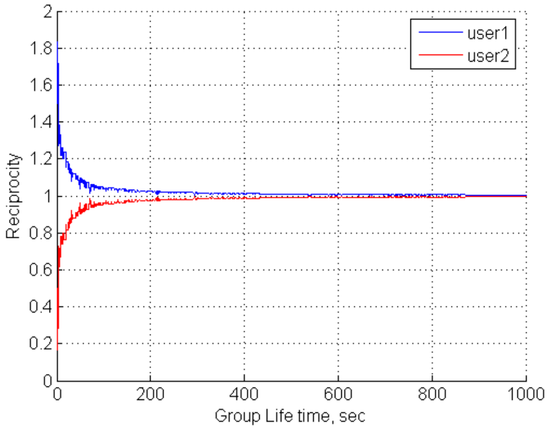

Figure 14. Reciprocity vs group life time. Packet Loss Rate = 1% and 3%. Payoff margin = 5.

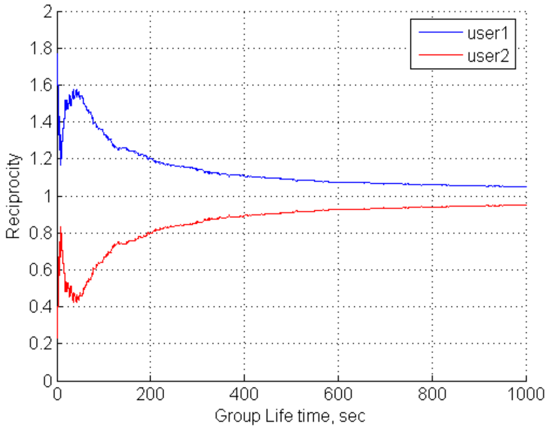

Figure 15. Reciprocity vs group life time. Packet Loss Rate = 1% and 3%. Payoff margin = 50.

[6] F.H.P. Fitzek, G. Schulte, M. Reisslein. System Architecture for Billing of Multi-Player Games in a Wireless Environment using GSM/UMTS and WLAN Services. Proceedings of the First Workshop on Network and System Support for Games (NetGames 2002), pages 58-64. Braunschweig, Germany. 2002.

[7] F.H.P. Fitzek and M. Reisslein. Ad Hoc technology in Future IP based Mobile Communication Systems. Proceedings of Wireless World Research Forum 5 (WWRF5). Tempe AZ, USA. 2002.

[8] F.H.P. Fitzek, M. Katz (Ed.). Cooperation in Wireless Networks: Principles and Applications. Springer. 2006.

[9] S. Frattasi, F. Fitzek, A. Mitseva and R. Prasad. A Vision on Services and Architectures for 4G. In 1st CTIF B3G/4G Workshop. Aalborg, Denmark. 2005.

[10] R. Axelrod. The Evolution of Cooperation. Basis Books. 1984.

[11] F.H.P. Fitzek and M. Katz. Cognitive Wireless Networks: Concepts, Methodologies and Visions Inspiring the Age of Enlightenment of Wireless Communications. 2007. Springer.

[12] F.H.P. Fitzek, T. K. Madsen, P. Popovski, R. Prasad and M. Katz. Cooperative IP Header Compression for Parallel Channels in Wireless Meshed Networks. In *IEEE International Conference on Communication (ICC)*, Seoul, Korea, 2005.

[13] F.H.P. Fitzek, S. Hendrata, P. Seeling, M. Reisslein. Chapter in Wireless Internet – Header Compression Schemes for Wireless Internet Access. CRC Press. 2004.

[14] DVB-H Implementation Guidelines, DVB-H Document A092, July 2005.

[15] J.William Atwood. A classification of reliable multicast protocols. IEEE Network, 18:24–34, 2004.

[16] R. Govindan D. Estrin P. Radoslavov, C. Papadopoulos. A comparison of application-level and router-assisted hierarchical schemes for reliable multicast. IEEE/ACM Trans., 12:469–482, June 2004.

[17] D. T. J. Nonnenmacher, E. W. Biersack. Parity-based loss recovery for reliable multicast transmission. IEEE/ACM Trans. on Networking, 6(4), August 1998.

[18] D. Zhu, M. Mutka, Promoting Cooperation Among Strangers to Access Internet Services from an Ad Hoc Network. Proceedings of the Second IEEE Conference on Pervacive Computing and Communications (PERCOM'04), 2004.

[19] Q. Zhang, F.H.P. Fitzek and M. Katz. Cooperative Power Saving Strategies for IP-Services Supported Over DVB-H Networks. In IEEE Wireless Communications and Networking Conference (WCNC 2007). 2007.