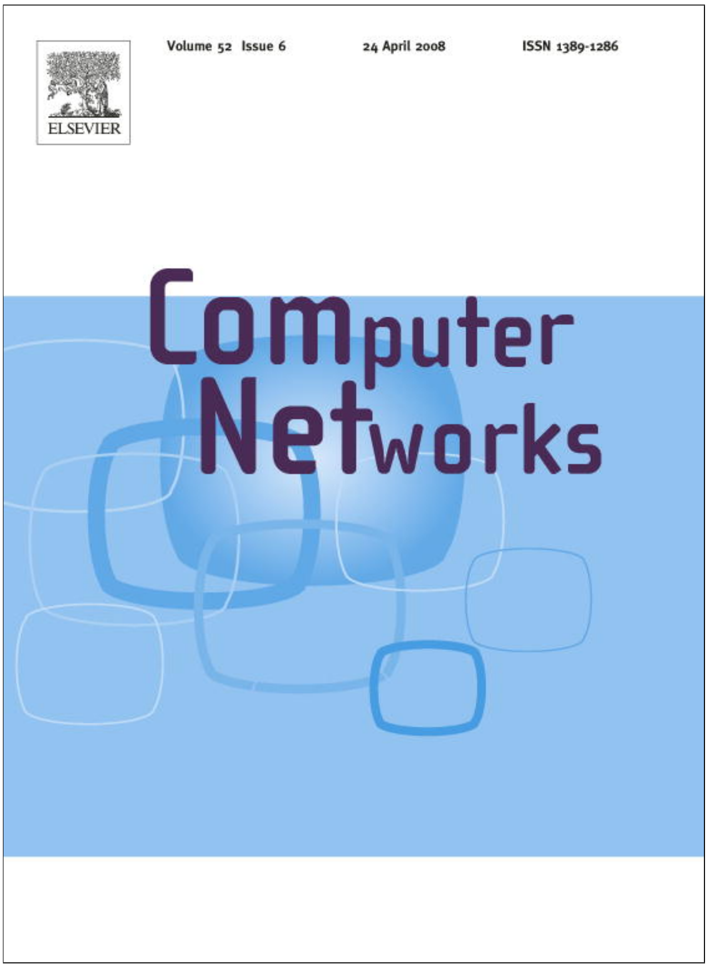
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Cooperative mobile-to-mobile file dissemination in cellular networks within a unified radio interface ☆

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Abstract

In this paper, a data dissemination technique is introduced for cellular networks by embedding peer-to-peer data transfer into the hierarchical architecture of UMTS (Universal Mobile Telecommunication Systems) for cooperative sharing of data among mobile terminals. Our concept is based on the uplink/downlink traffic imbalance in 3G wireless networks and clearly confirms the social principle "real egoistic behavior is to cooperate". It boosts the spectral efficiency of UMTS by enabling direct mobile-to-mobile data transfer and by dynamically allocating users to temporarily unused uplink channels. The results indicate a substantial increase in service probability and overall system throughput, as well as a significant reduction of the expected file download time.

Keywords: Cooperative file dissemination; UMTS; Traffic imbalance; Spectral efficiency

1. Introduction and motivation

Currently the telecommunication infrastructure is characterized by a rapid growth of new high data rate fixed-line services. Such observations motivate operators of wireless networks to extend their business models by offering new data applications, such as real-time streaming, distributed video conferences, as well as downloading popular movies or music files.

One of the main problems of cellular networks is the relatively limited transmission capacity. Typically, the downlink is the potential bottleneck, since all data transmissions have to be organized by providing individual links from a base station (BS) to each user. As a result, the radio interface quickly becomes saturated, which leads to degradation or even loss of the service.

In general, services can be divided in two groups: real-time and non-real time demands. The main distinguishing factor between these service classes is their delay sensitivity. The so-called streaming class as a subgroup of the former is very delay sensitive,

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while the background class belongs to the latter and is delay insensitive. Although the data content of the latter service type, like digital camera images, demo versions of programs for popular handset games and mp3 files, is interesting for many users, conventional solutions for capacity utilization such as multicast or broadcast are not applicable since users may request services at different times.

Currently, there are two main concepts by which the performance of wireless systems can be enhanced: complementary networks with multi-mode mobile terminals (MT) or cooperative networks, where the same radio interface can be used for different networks. Both focus on the efficient realization of a flexible radio interface and network architecture.

The main idea behind the first approach is to exploit available technologies. By implementing several radio interfaces in one device, the network operator can provide users with a seamless connectivity to data, i.e. users can proceed to be active as they roam between networks, which is very important for real-time data session continuity.

An alternative way to support an expanding variety of data applications in the 3G of cellular radio networks is to extend their existing radio interface, thereby enabling it to support different network architectures in a dynamic way.

One of the interesting research directions is to consider the relationship between the two network concepts, client–server and peer-to-peer. The client–server system model has a centralized structure, where clients communicate only with the server and never with each other. A typical example for client–server networks is a cellular network. On the other hand, the peer-to-peer system model allows a direct communication between users in an ad hoc manner with minimum infrastructure. Each user offers both client and server functionality (e.g. fixed-line peer-to-peer Internet protocols like *BitTorrent* [1], *eDonkey* [2], etc.).

Typically, these two network approaches were considered as competing, though, given the significant support of both concepts by the industry, most recent visions tend to regard them as complementing each other. Recently, even more progressive studies are investigating the effect of the synergetic cooperation between the above mentioned networks by using a unified radio interface.

These visions are illustrated in Fig. 1, where the differences of the contending network solutions are highlighted [3].

What is the actual benefit of cooperation in wireless networks?

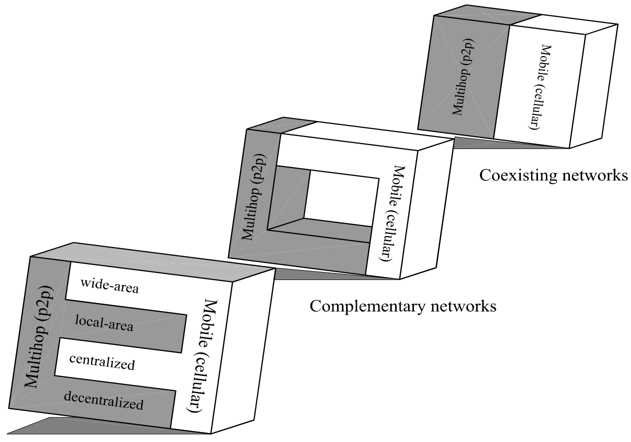

Fig. 1. Visions of the contending network solutions.

One of the primary bases for network cooperation is to fully exploit the available technologies, increase efficient usage of frequency spectrum, as well as reduce infrastructure costs.

The motivation for cooperation between cellular wireless and peer-to-peer networks is the predicted ability of peer-to-peer systems to complement conventional cellular networks in areas with poor coverage, as well as in high user density areas. Owing to direct communication between MTs, there are substantially more sender-receiver pairs than in conventional cellular networks, where the data transmission is organized by providing individual links from the base station to each user. Thus, such a hybrid network structure is capable of increasing the number of MTs that can be simultaneously handled in peer-to-peer mode.

In addition, the peer-to-peer network approach provides a further advantage. Due to the short range between MTs, the interference is expected to be lower, which leads to an increase in capacity and an improved QoS.

On the other hand, also peer-to-peer networks can benefit from the existing infrastructure of cellular networks. Peer-to-peer networks have to tolerate an increased communication traffic so that they will be able to use a decentralized structure: distributed peers generate a considerable amount of signalling traffic for coordination between them. This drawback can be mitigated by taking advantage of already existing infrastructure of cellular communication systems. For example, network operators know the location, online status and service agreement of the mobile users. They can utilize this knowledge by providing each new user with information about all active users in the system in the range of tens of meters, to determine the potential cooperative community. Such an explicit use of the hierarchical cellular infrastructure leads to more efficient and reliable routing and significantly lowers the protocol complexity.

Complementary and cooperative network approaches have been recently proposed for various wireless communication systems with the purpose to improve network coverage as well as individual and aggregate throughput of users.

The feasibility of the extended *eDonkey* peer-to-peer file sharing Internet protocol in a GPRS (General Packet Radio Service) environment was investigated in Ref. [4] and appropriately modified for UMTS radio networks in Ref. [5]. The main focus lies on resource mediation (functions to locate resources or entities) and resource control mechanisms (functions to permit, prioritize, and schedule the access to resources) by using different strategies for data caching in the wired part of the network. The specialized fixed-network cache peer stores popular files in the network in order to avoid downloading content from the BS which has been already downloaded.

An interesting idea for traffic balancing was also proposed in Ref. [6]. The main focus lies on improving call blocking probability for circuit-switched traffic by diverting traffic from a congested cell to a neighboring lightly loaded cell, introducing strategically located stationary ad hoc relays. The concept is referred to as iCAR (integrated cellular and ad hoc relay system). However, the placement of fixed relays in specific location is necessary for successful use of the algorithm, i.e. at every border of two adjacent cells, it is not always possible due to legal issues, e.g. government laws and regulations, or security of private companies. Moreover, the deployment of additional equipment always incurs an extra cost.

In our proposed concept the mobile terminals (MTs) operate in peer-to-peer communication mode for cooperative distribution of popular content, i.e. they act as both client and server.

Similar techniques have been used in Ref. [7,8], where the authors allow MTs to act as ad hoc relay stations in order to improve their data throughput. In Ref. [8] it was shown how UMTS capacity can be improved by embedding WLAN (wireless local area network) systems, whereas the authors in Ref. [7] propose a unified cellular and ad hoc network architecture (UCAN) with combination of EV-DO (evolution-data only)[1] and IEEE 802.11b (Wi-Fi) networks for an ad hoc data transmission mode. The results indicate noticeable throughput gains. However, two radio interfaces have been used to switch between networks, which implies that additional resources from alternative network(s) are taken. Further references can be found also in Ref. [9].

The key difference between the cited above studies and our work lies in the basic principle of capacity improvement techniques in wide-area cellular networks. In all mentioned above network scenarios an additional frequency band of some local-area networks was used in order to achieve an improvement in individual and aggregate throughput of cellular users.

In our work, instead of involving external resources, e.g. borrowing frequency, we utilize the available frequency spectrum within cellular networks which is typically underused in the uplink with the purpose to improve the system performance, e.g. the number of simultaneously served users, individual and aggregate throughput and QoS. Unlike to try to balance traffic by rerouting connections from overloaded to underloaded cells, as it was proposed in iCAR, we leverage the specific property of UMTS FDD (frequency division duplex) mode, namely, its paired spectrum allocation principle. UMTS FDD uplink and downlink is designed to operate in two specified symmetrical frequency bands. Using our knowledge about highly asymmetric traffic distribution of data services between uplink and downlink we exploit the normally underused uplink frequency band for a group-based cooperative mobile-to-mobile data dissemination on the currently free uplink channels.

To the best of our knowledge, the closest work to ours is Ref. [10], where the traffic load imbalance in the UMTS uplink/downlink has been exploited as well. The idea of this study is to put an UTRA-TDD (time division duplex) link into the underused UTRA-FDD (frequency division duplex) band. On the border of an UTRA-FDD macro cell an ad hoc pico cell with MTs, operating in TDD mode, is organized. One of these MTs is designated to act as a gateway to the BS and, thus, to the backbone network. It was shown that such an architecture has a potential to improve the system throughput, as well as to increase service probability on the cell border.

However, a shortcoming of the proposed solution [10] is the strong dependency between the two system modes and corresponding requirements of efficient coordination of their functionality. For example, the amount of FDD uplink resources to

[1] Integral part of the CDMA2000 (code division multiple access) family of 3G standards.

be used for the TDD mode has to be determined. Moreover, special consideration needs to be given to the functionality of the gateway MT. To avoid collisions between several gateway MTs and to arbitrate their interference to the MTs in the pico cells, time slot synchronization is required and the maximum number of gateway MTs has to be controlled.

The above mentioned drawbacks can be circumvented by our new solution, where a unified radio interface is used for both conventional cellular and peer-to-peer system modes.

Furthermore, the above mentioned studies aim at fitting the QoS to service categories where each user is individual with personal and somewhat unique needs. This makes the users' incentives to cooperate not necessarily apparent.

Our hybrid network architecture is developed for efficient distribution of popular non-real time data content, which is interesting for many users. Thus, users are strongly motivated to act in a cooperative manner in order to reconstruct content of common interest effectively. Our algorithm yields significant relative cell throughput gain in number of MTs, that can be simultaneously served, as well as individual user throughput gains by exploiting the underloaded uplink frequency band, without requiring additional equipment or resources from other (external) networks.

The rest of the paper is organized as follows. In Section 2, we propose a novel technique for the integration of peer-to-peer applications into cellular wireless networks. Details of the proposed technique are given in Section 3. Numerical results for a UMTS network scenario are discussed in Section 4. Finally, we conclude the paper by pointing out some future research directions in this area.

2. Direct mobile-to-mobile data exchange concept

2.1. Benefits of mobile-to-mobile technique

To overcome the capacity limitations of UTRA-FDD[2] and to release overall downlink capacity of the system we developed a hybrid technique of efficient distribution of popular non-real-time data contents in order to optimize the data availability to users in high user density areas (hotspots). It is an appealing scenario for, e.g. airport lounges, railway stations, shopping malls, where users increasingly demand ubiquitous data availability.

We leverage a specific property of the UMTS FDD mode, namely its paired spectrum allocation principle. UMTS in FDD mode operates in two distinct symmetrical frequency bands per cell and operator.

The proposed concept is based on cooperative exchange of data among users in (direct) mobile-to-mobile (m2m) mode on currently unused UMTS uplink channels and is realized by integrating a peer-to-peer technique into the existing cellular structure of UMTS networks.

Although, due to the distributed time of users' service requests, conventional solutions for capacity utilization such as multicast or broadcast are not applicable, one can handle a background user as a member of a distinct group with some common characteristics.

Our concept properly exploits the above mentioned setup for background service types. Namely, the users that are interested in downloading a popular file, for example a movie trailer or the latest computer games, form a mobile cooperative community (groups). By using the fact that traffic load of multimedia services is asymmetrically distributed between uplink and downlink they contribute their own normally only partly used uplink capacity for providing the packets of the content they have to other users in the group (in their coverage range) in multicast mode on the typically underused uplink carrier frequencies.

Instead of serving all background users which are interested in downloading a popular content simultaneously by transmission of the complete data file to each MT individually, the original popular file, which is available somewhere in the network, is divided into m logical packets, each with an individual ID. Each logical packet is then distributed by the BS only once to one of the above mentioned users, in general each packet to a different user, by organizing dedicated channels for a short period of time. After that, none of the users has the complete desired file, but only a small random set of single packets. Nevertheless, in summary all packets, i.e. one complete copy of the file, are now present within a radio cell.

A user who received a packet from the BS can act as a server for that particular packet on his own currently not used uplink channel. Hence, the users start to cooperate with each other for exchanging packets, being organized into dynamically reshaped multiple groups with the purpose to reconstruct the original file of interest. The mobile terminals are

[2] FDD mode of WCDMA.

assumed to be able to receive in both uplink and downlink bands and each new user brings further uplink resources into the system.

Now the reasonable question can arise, what are the incentives for users to cooperate? Why not use conventional solutions for capacity utilization such as multicast or broadcast?

Although background services such as digital camera images, mp3 file or movie trailers downloads are interesting for many users, the mentioned above conventional methods are not applicable since users request service at different times. As a result, after distributing the file by organizing, e.g. a broadcast channel, there will be quite many users in the network without any information about the popular file (due to the distributed time of users' service requests), and users with a complete copy of data. The latter will leave the system immediately after finishing their download due to the lack of incentives to relay their data on behalf of the less "lucky" mobile terminals, which came into the network later during the last phase of the file broadcasting.

In our concept, the fact that none of the users receives the complete file directly from the BS via, e.g. a broadcast channel, mitigates the lack of user's willingness to cooperate, thus providing strong motivation for file-sharing-participants to become a server for distribution of the packets of the particular popular content. A user decides to send the packet to another user in the group for his own potential advantage. Investing some battery life, he may not have an immediate gain, but looks ahead to a point in time he will have packets to receive from other users in the group.

By adopting this cooperative data transfer among users, the BS does not need to provide conventional unicast links of long duration to each user, saving valuable downlink resources, consequently. Thus, a major part of the traffic is shifted away from the downlink, making the released downlink capacity available for other (e.g. real-time demand) services.

The proposed file sharing technique is hybrid: the search of the participants in m2m file transfer, who are looking for the same content is centralized (BS) and the transfer is distributed (m2m). Thus, by combining the intelligence of the cellular network (fixed infrastructure and centralized control of BS) and the flexibility and distributed nature of peer-to-peer networks, we utilize normally underused uplink capacity in UTRA-FDD and in turn, improve the system capacity in terms of cell throughput (in both number of MTs that can be simultaneously handled and in amount of data), individual users' data throughput, QoS, etc.

In this work we evaluate the performance of a novel m2m algorithm for a UTRA-FDD scenario, taking into account the specifics of UTRAN, e.g. wireless interference, a realistic propagation model, etc. However, the principle can be applied to other systems as well.

2.2. m2m Concept

To enable the cooperative peer-to-peer technique in wireless networks we revisit the idea of a mesh architecture for the fixed-line Internet [1] and appropriately extend it for the UTRA-FDD. To illustrate the main concept of the m2m technique, consider the example in Fig. 2. MTs voluntarily participate in file sharing via direct mobile-to-mobile data transfer with the purpose to reconstruct the original popular content, which is distributed in the network.

- Upon arrival, each new user, who is interested in downloading popular content, establishes contact to the BS/RNC (radio network controller) in order to get an authorization to participate in m2m file transfer and to get a random packet of the desired file together with information about nearby located m2m users, which are interested in the same popular content.
- In a cellular wireless system, in contrast to wireline Internet peer-to-peer applications, the number of users who can cooperate with each other is limited by the transmit power of the MT and its coverage range, which will be typically less

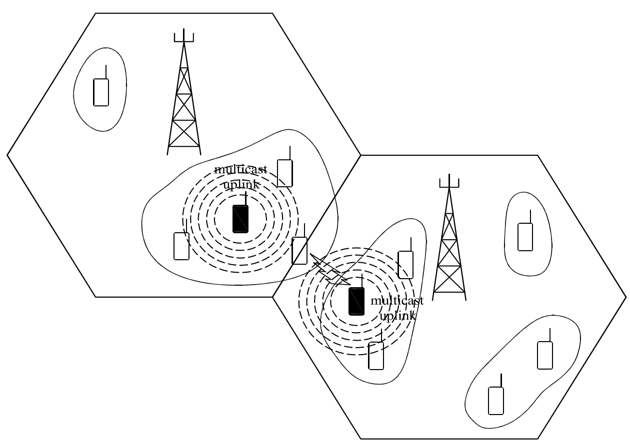

Fig. 2. m2m Concept.

than a cell. Therefore, in case of a wireless cooperative community formation, mobile communities are location and radio propagation dependent. Thus, to cooperate with each other, m2m users must be organized into groups.

- The simplest way to inform a new MT about all other MTs requesting the same content in its coverage range is to transmit "Hello" packets by all MTs periodically. But this procedure puts considerable load on signalling channels. Thus, taking into account that a wireless system is limited by the available frequency spectrum, it would be more efficient if upon arrival each new m2m user contacts a BS that provides information about all other m2m users already in the system in the range of tens of meters, to determine the potential members of the group. This can be done by using, e.g. GPS (global positioning system) or triangulation techniques [11]. In case no appropriate group for a new user is found it forms a group with a stand-alone user only. Only MTs assigned to a multiple member group send a "Hello" packet to get an appropriate information about the pathloss to any other MTs from its group. In such a way the signalling information between stand-alone MTs can be reduced.
- Users dynamically join and leave the group at any time (battery life, handover), representing a relatively loosely coupled formation.
- Groups are periodically updated and reshaped in order to check the positions of MTs and their radio propagation characteristics on the one hand, and to track and authorize new m2m users in the group in case they fulfil the above mentioned "join-group" criteria on the other hand.
- Information about the link quality can be derived from, e.g. "Hello" packets, periodically transmitted by MTs.
- The size of the groups is limited. Each MT can be a member of only one group at a time. The group members are not restricted to belong to the same cell. However, the BSs, to which these MTs are assigned must belong to the same radio network controller (RNC). Otherwise, the grouping is restricted to members of the same radio cell.[3]

[3] A strictly RNC-based group organization policy is chosen in order to avoid possible collisions of signalling information in practical implementation of the file sharing protocols.

Fig. 3 visualizes the basic order of message sequences during the very first stages of the cooperative m2m data exchange.

3. m2m Algorithm

Using the m2m service, each authorized m2m user must allow the use of his currently not occupied uplink capacity by providing the packets of the content he requested to other m2m users which are interested in it (service level agreement).

3.1. Data exchange policy

We assume that each user knows about the packets he has downloaded and the IDs of the packets that are available at its neighbours (the information can be sent in "Hello" packets).

- Initially, the original file is available in the core network only.
- In order to avoid packet collisions, to reduce the transmission of identical packets on the network links and in turn to increase the efficiency of usage of scarce and asymmetrically loaded uplink/downlink, the m2m data transfer is performed in the multicast mode among users within a group on the uplink carrier frequency, whereas receivers in the group switch to listen on the uplink.Such a parallel packet downloading policy improves the performance of the system in terms of number of simultaneously served m2m users.
- Identification of the sender is done using a unique scrambling code. The MTs must be able to receive in both uplink and downlink bands.

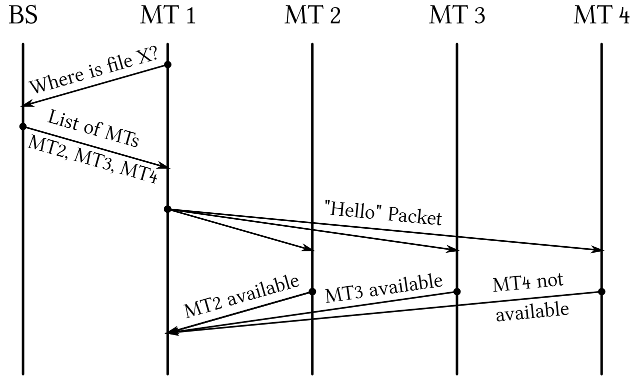

Fig. 3. Signalling message sequence for setup of communication between m2m users.

- BS supports intra-group data transfer with signalling information, such as "change your mode", "listen for this scrambling code", "listen on the uplink frequency". In case members of some group are assigned to different BSs, they will be coordinated (supported with necessary information) via the RNC that is responsible for the set of BSs.[4]
- To make m2m transmission as effective as possible, the data exchange algorithm, performed at the BS, finds an appropriate "sender" candidate, based on a local "most-utile-packet" scheme, in order to maximize the number of users for which the packet can be useful.
- No physical data channel on the BS is needed to control the data exchange process in the group.
- After the best candidate is found, the admission control procedure verifies whether the system has enough uplink capacity to accept the connection. In case more than one relevant "sender" candidate within a group was declared by the data exchange algorithm the sender will be chosen at random. If a sender has more than one packet to send, the packet with the lowest ID will be distributed first.
- In order to avoid collisions on the uplink channels of each group, the BS allows only one MT within a group to transmit in each time interval. As a result of BS signalling, each MT knows whether it has to transmit or to listen. This procedure is performed framewise, which means, that in each group only one sender can be active within a frame.[5]
- Users who have not found any useful packets within a specified time interval try to connect to the BS for packet delivery.

The following flow chart visualizes the data exchange mechanism (see Fig. 4).

One of the main problems of cellular networks is the interference. To avoid interference from MTs transmitting in m2m mode on other signals at the BS receiver, the transmit power is set to the minimum. To avoid packet collisions caused by wireless interference from other groups, it is necessary to estimate the optimal group size, which will be discussed in the next section.

[4] Due to the RNC-restricted group organization policy the probability of some collisions caused by using the same uplink channel in two or more neighboring groups is very low. Moreover, in the unlikely event that an uplink channel collision occurs, the probability that these groups are in close vicinity is negligible.

[5] In this work, we have assumed that the size of a logical packet is equal to one UMTS radio frame. However, for other packet sizes the algorithm can be executed as well.

4. Performance of m2m data transfer

In this section, we present some numerical results to highlight the effectiveness of the proposed m2m technique. We used a time-driven simulator and carried out comprehensive simulations. The simulated network consists of regular hexagonal cells. A wrap-around technique is used to avoid border effects.

4.1. Basic functionality: comparison of m2m file sharing with conventional UMTS data transmission

In order to validate the advantages of using m2m mode in the UMTS network for distribution of popular non-real time content in terms of its basic functionality, we compared its performance with that of the conventional downlink unicast mode.

We consider four performance measures:

- Overall downlink throughput gain: data volume reduction in the downlink.
- Service probability gain: increase in the number of served users (%).
- Download time gain: download time reduction. We define the download time as the time window, in which the user receives the complete file. The criterion for the download time gain is the 90% quantile of finished downloads in the system.
- Relative losses of link quality: number of corrupted data in (%).

We list now the assumptions and parameter settings we employed in our simulations:

- We simulate a population of users with Poisson distributed service requests, that are interested in downloading a popular file. The MTs are distributed randomly over the cell area. Each MT has a given constant speed during a simulation session. All users are assumed to be pedestrians.
- The main focus of our analysis lies in the optimization of data availability to users in hotspots. The radius of the cell is 50 m.
- We assume that there is mobile specific content type of 500 Kbyte size to be distributed with the m2m strategy.

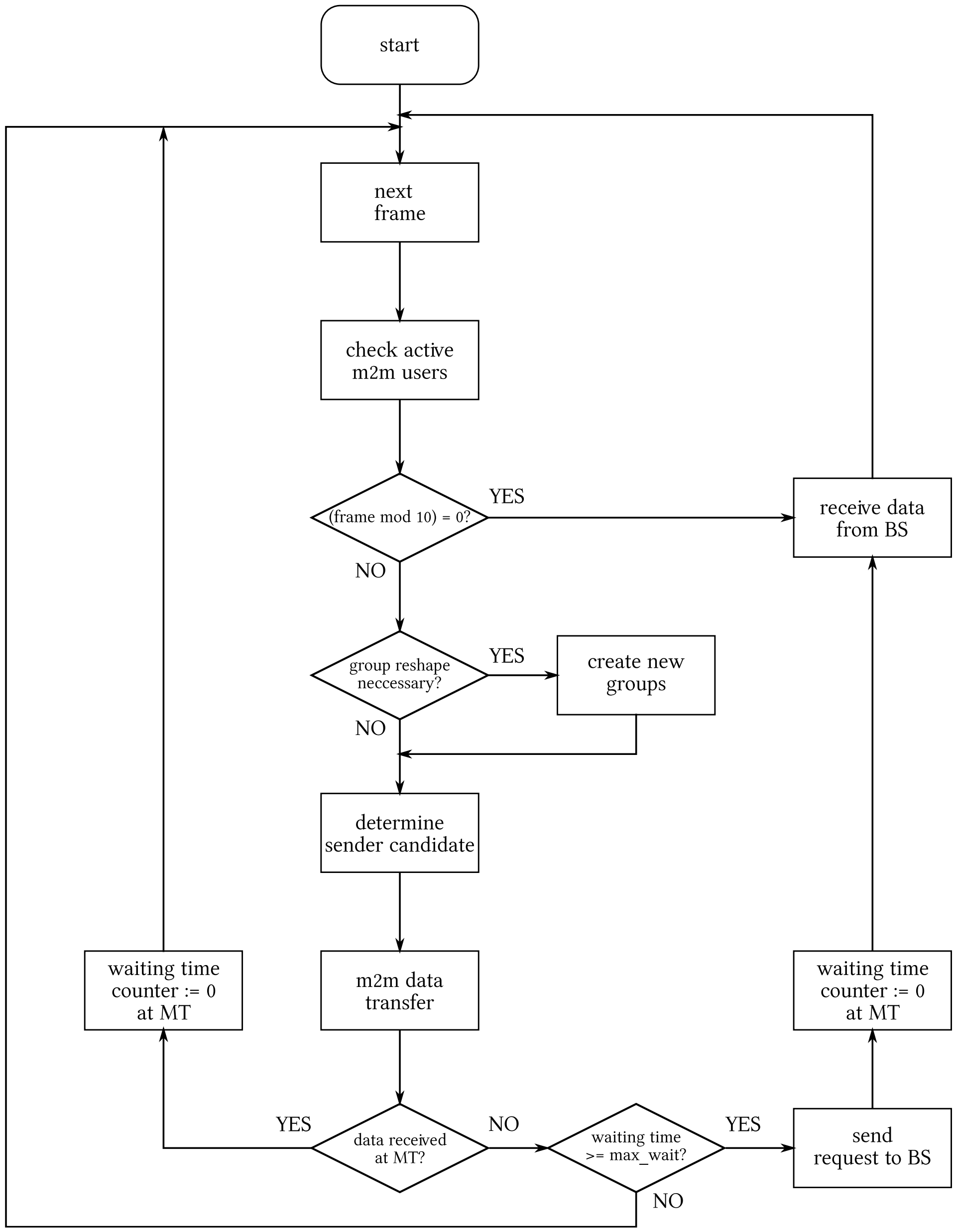

Fig. 4. Flow chart of m2m file sharing.

- The size of the groups is restricted to seven members for the time being.
- The MTs depart from the system immediately after finishing their download.[6]
- The size of a logical packet is equal to one UMTS radio frame, i.e. 225 encoded and spread bits.[7]
- An appropriately modified radio propagation model for low antenna heights for both, transmitter and receiver was used. In order to avoid interference from MTs transmitting in m2m mode on other signals at the BS receiver, the transmit power is set to the minimum, which is −44 dBm according to 3GPP specifications [12].
- The characteristics of the wireless channel in each group can vary from slot to slot (fast fading).

[6] However, this assumption is not strictly required and can be relaxed. Then, users which have already finished their downloads may stay in the system for a while to speed up the distribution of missing packets to still not finished users. This is, however, a kind of so-called enlightened self interest. Therefore, external reward schemes might be needed to motivate the users to stay and help, e.g. upload credits.

[7] Depending on the coding scheme and spreading factor this leads to corresponding packet sizes of information symbols.

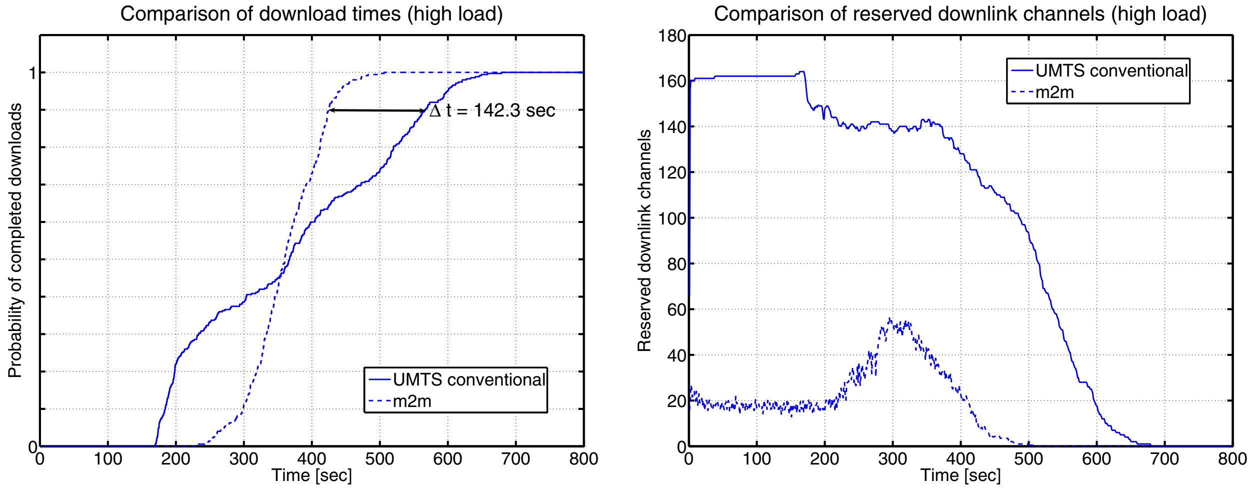

Fig. 5. Performance comparison of conventional and m2m mode for high traffic load versus file download time.

- Information about the quality of the multicast signal within the group is obtained based on the ratio of the average received power of the useful signal to that of all relevant interfering signals (C/I) on a slot-by-slot basis.
- The BS/RNC responsibilities are (1) to distribute at least one complete copy of the original file in every radio cell (time interval between BS "packet upload sessions" is 10 radio frames), (2) to support the data exchange process in the m2m groups with signalling information, and (3) to serve timeout requests from MTs.
- If the packet is incorrect after detection, we declare a packet loss.[8]
- The simulation time is 400–1200 s and we collect data framewise.

The left graph of Fig. 5 demonstrates the efficiency of the m2m file sharing mechanism for heavy traffic load (50 m2m users/cell) in terms of the download time reduction. The right one depicts the m2m performance gain in terms of released downlink resources.

We observe that at least 90% of all users experience a reduction of the download time for the complete file of up to 21%. Furthermore, up to 85% of the downlink capacity is released in a UMTS network, supported by m2m data transmission mode compared to the conventional UMTS mode.

The shape of the curves around the time instant of 300 s is due to the fact, that the majority of m2m users (dashed line) have completed their download until above mentioned time and leave the system. This forces the remaining users to connect to the BS for further packet delivery more frequently, which obviously puts additional load on downlink resources. In case of the conventional mode of data transfer (solid line), since some part of the users have successfully finished their data reception around the mentioned above point in time, one can observe that the curve starts to decay. It is evident, that the more finished users leave the system, the more downlink capacity is released.

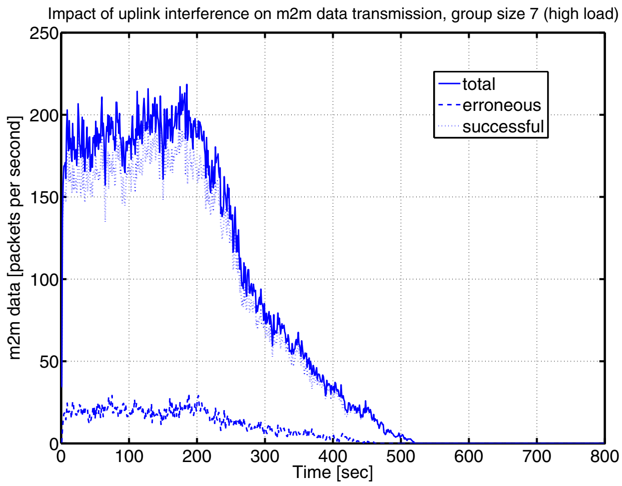

Fig. 6. Impact of uplink interference on m2m data transmission for group sizes 7 in a high loaded UMTS system.

4.2. Impact of group size

We examine now some parameters and their influence on the system performance. We consider

[8] If up to a third of the frame (1 frame = 15 slots) is corrupted, caused by an unacceptable C/I level, transmitted data is still assumed to be recoverable (due to channel coding).

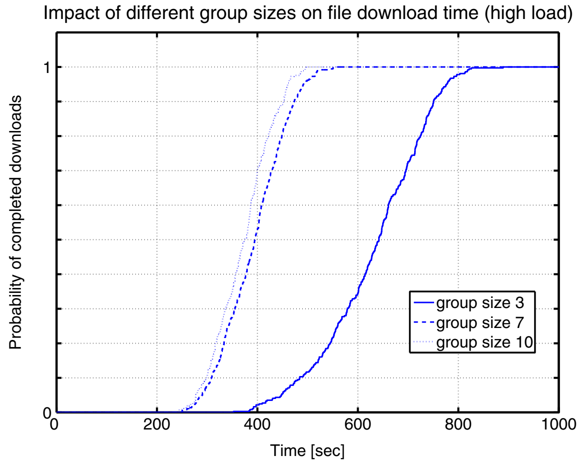

Fig. 7. Impact of the group size on the file download time for high traffic load.

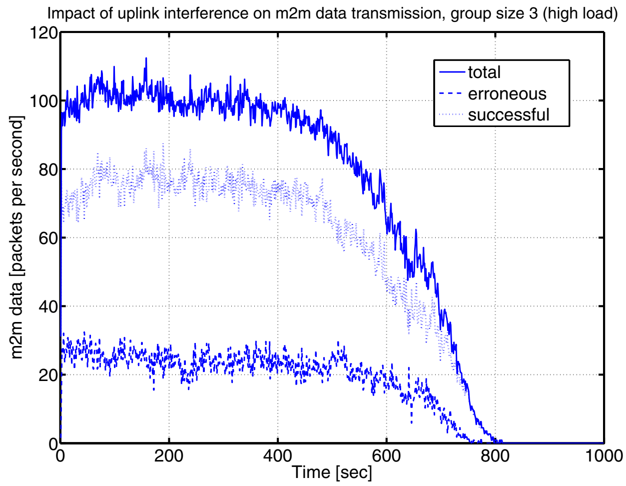

Fig. 8. Impact of uplink interference on m2m data transmission for group sizes 3 in a high loaded UMTS system.

again the same m2m scenario with maximum group sizes 3, 7, 10 and investigate the effect of the group sizes on the performance of the proposed technique for low, medium and high traffic load. In Fig. 7 the influence of the group sizes on the file download time for a high loaded UMTS system is illustrated.

Intuitively, the larger the group size, the higher the multicast efficiency. The number of needed senders is lower, hence, for the same number of members in the system large groups consume less bandwidth. Equivalently, with the same uplink resource consumption more members will get service when the group size is larger.

With increased number of multiple coexisting groups (group size 3) in the network some performance degradation of the m2m technique is observed. This effect is influenced by admission control, wireless interference and user mobility. Obviously, with increasing the number of groups the number of sender candidates that can be admitted is bounded by the uplink capacity. This results in a rejection of some link admission requests of sender candidates. Besides, if the group size is too small and the mobility of users is low (as assumed in this work), the probability to find a missing packet in each frame is quite low; the number of packet requests from m2m users to the BS increases and puts additional load on the downlink resources.

Another important performance criterion is the average rate of the successfully delivered packets. For systems with small group size we observed enormous m2m uplink interference, which leads to significant performance degradation and in turn to an increase of download time.

Figs. 6 and 8 demonstrate the impact of the uplink interference on m2m data transmission for group sizes 7 and 3 in a high loaded UMTS system (effective user data rate is 30 kb/s).

The probability of losses of link quality (number of corrupted data in %) for different group sizes and traffic scenarios are shown in Table 1.

4.3. Efficiency and dependability

The results presented in the previous subsection demonstrate the performance of the m2m algorithm for a simple scenario with m2m file sharing participants only. In this subsection we analyze the applicability of the m2m technique in a real world scenario in the presence of speech-traffic (cross-traffic) by addressing efficiency and dependability issues. Since the speech users operate on the same uplink frequency as the m2m users, the signals they generate in the uplink are a potential source of disturbance for the m2m signals, that can lead to further performance degradation of the m2m data transfer. We outline several mixed traffic scenarios to investigate the reliability of the proposed m2m concept and its robustness to wireless interference.

Table 1
Impact of uplink interference for different group sizes and traffic scenarios (erroneous data [%])

Scenario	Erroneous data (%)		
	Group size 3	Group size 7	Group size 10
Low load	3.71	1.86	2.07
Medium load	13.70	5.56	6.25
High load	18.96	8.88	8.99

For these scenarios we assume that service requests for speech users are served in conventional mode, where individual links are organized from the BS to each user. The network architecture is assumed to support two alternative modes of serving user requests (m2m network mode and conventional UMTS mode). The transmission in conventional mode complies with 3GPP specifications for UTRA-FDD.

We analyze the following traffic scenarios:

Scenario 1: The number of speech users per cell is kept constant (approx. 3 speech user per cell), while the load of m2m users is varied.

Scenario 2: The amount of speech traffic varies proportionally to the m2m traffic load, with the mean number of speech users being 20% of the mean number of m2m users in a cell. For low load, this results in 2, for medium load in 6 and for high load in 10 active speech service sessions per radio cell.

Scenario 3: The same characteristics as Scenario 2, however, with increased intensity of 40% for speech users, i.e. 4 (low load), 12 (medium load) and 20 (high load) active speech users per radio cell.

The parameters that are of interest are the released downlink transmission capacity, as well as the service probability gain. Some numerical values for the overall downlink throughput gain with respect to complete file download in m2m network mode with and w/o cross-traffic are compared in Table 2 with values for conventional UMTS data transmission. The table also shows how many Mbyte of data had to be sent via the downlink channels in order to distribute the data file of 500 Kbyte size to the users within one cell.

It is evident, that the higher the cross traffic load and thus the level of interference, the more data is corrupted. All this forces m2m users to request packets of the desired file from the BS more frequently, which in turn impairs the efficiency of the m2m concept.

Nevertheless, the direct comparison of the m2m performance results with those for the conventional UMTS data transmission demonstrates an overall downlink throughput gain of up to 85%, obtained by using the m2m technique.

Table 2
Overall downlink throughput gain: data volume in downlink in m2m mode for different traffic scenarios and service probability gain (for users within one cell)

Load	Low	Medium	High
Data volume in DL in conventional mode [MB/cell]	5.73	16.51	34.44
Data volume in m2m mode w/o cross-traffic [MB/cell]	1.94	2.63	5.31
Released downlink capacity [%], (w/o cross-traffic)	66.14	84	84.6
Scenario 1: cross-traffic 3 user/cell [MB/cell]	2.03	3.25	5.89
Released downlink capacity [%], Scenario 1	64.5	80	82.8
Scenario 2: cross-traffic 20% of the mean number of m2m user/cell [MB/cell]	1.98	3.42	6.33
Released downlink capacity [%], Scenario 2	65.4	79.2	81.6
Scenario 3: cross-traffic 40 % of the mean number of m2m user/cell [MB/cell]	2.09	3.69	7.23
Released downlink capacity [%], Scenario 3	63.5	77.6	79
Service probability gain [%], (w/o cross-traffic)	46.92	58.40	67.30
Service probability gain [%], Scenario 1	30.06	52.23	66.53
Service probability gain [%], Scenario 2	33.02	47.15	64.16
Service probability gain [%], Scenario 3	29.23	44.56	61.19

The last four rows in the table shows the relative gain in the number of MTs, that can be supported by the m2m concept in the presence of speech-traffic.

5. Conclusions

In this paper, we have shown how cooperative behavior of wireless users can substantially improve the efficient usage of frequency spectrum in cellular networks.

We introduced a new hybrid technique for efficient distribution of popular non-real-time data content in order to optimize the data availability to users in hotspot scenarios. The proposed concept is based on integrating a peer-to-peer technique into the existing cellular structure of the UMTS network in order to realize a direct m2m cooperative data exchange on UMTS uplink channels.

Simulation results demonstrated that the proposed cooperative approach is capable to improve the performance of a cellular wireless system considerably. It has been shown that a cellular network, supported by our cooperative solution significantly outperforms a network in conventional UMTS mode and might be a promising alternative for distribution of content in cellular radio networks like UMTS.

Thus, by leveraging flexibility of peer-to-peer networks with their minimal infrastructure and by combining this with the intelligence of centralized controlled cellular networks we get a scalable system which is able to support a large range of wireless services.

Among the open research problems, properly designed scheduling of the packet transfer stands out as a challenging task that has significant impact on the efficiency of the content distribution in terms of expected download times and on corresponding improvement of the system throughput.

Even though cooperation in wireless communications has not reached its full maturity yet, its realm is already broad.

References

[1] B. Cohen, Incentives build robustness in BitTorrent, in: Workshop on Economics of Peer-to-Peer Systems, Berkeley, CA, USA, May 2003.
[2] J. Lloret, J.R. Diaz, J.M. JimTnez, M. Esteve, Public domain P2P file sharing networks content and their evolution, in: Proceedings of the IEEE Communication Systems and Networks (CSN), Benidorm, Spain, September 2005.
[3] F.H.P. Fitzek, M.D. Katz (Eds.), Cooperation in Wireless Networks: Principles and Applications, Springer, 2006.
[4] T. Hossfeld, K. Tutschku, F. Andersen, H. de Meer, J. Oberender, Simulative performance evaluation of a mobile peer-to-peer file-sharing system, in: Proceedings of the IEEE Next Generation Internet Networks (NGI), Rome, Italy, April 2005.
[5] T. Hossfeld, K. Tutschku, F. Andersen, Mapping of filesharing onto mobile environments: enhancement by UMTS, in: Proceedings of the IEEE Pervasive Computing and Communications (PerCom), Kauai Island, Hawaii, March 2005.
[6] H. Wu, C. Qiao, S. De, O. Tonguz, Integrated cellular and ad hoc relaying system: iCAR, IEEE Select. Area Commun. 19 (10) (2001) 2105–2115.
[7] H. Luo, R. Ramjee, P. Sinha, L. Li, S. Lu, UCAN: A unified cellular and ad-hoc network architecture, in: Proceedings of the ACM MOBICOM, San Diego, California, USA, September 2003.
[8] D. Tacconi, C. Saraydar, S. Tekinay, Ad hoc enhanced routing in UMTS for increased packet delivery rates, in: Proceedings of the IEEE WCNC, New Orleans, USA, March 2005.
[9] D. Cavalcanti, D. Agrawal, C. Cordeiro, B. Xie, A. Kumar, Issues in integrating cellular networks, WLANs, and MANETs: a futuristic heterogeneous wireless network, IEEE Wireless Commun. Magaz. 12 (2005).
[10] H. Haas, G.J.R. Povey, A capacity investigation on UTRA-TDD utilising underused UTRA-FDD uplink resources, in: IEE Colloquium on UMTS Terminals and Software Radio, Glasgow, UK, April 1999.
[11] G. Swedberg, Ericsson's mobile location solution, Ericsson Review 4 (1999).
[12] "UE Radio Transmission and Reception", 3GPP TS 25.101.

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