Chapter 19
Cooperative Communication System Architectures for Cellular Networks

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ABSTRACT

An ever-growing demand for higher data-rates has facilitated the growth of wireless networks in the past decades. These networks, however, are known to exhibit capacity and coverage problems, hence jeopardizing the promised quality of service towards the end-user. To overcome these problems, prohibitive investment costs in terms of base station or access point rollouts would be required if traditional, non-scalable, cell-splitting, and micro-cell capacity dimension procedures were applied. The prime aim of current R&D initiatives is, hence, to develop innovative network solutions that decrease the cost per bit/s/Hz over the wireless link. To this end, cooperative networks have emerged as an efficient and promising solution. We discuss in this chapter some key research and deployment issues, with emphasis on cooperative architectures, networking, and security solutions. We expose some motivations to use such networks, as well as latest state-of-the-art developments, open research challenges, and business models.

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INTRODUCTORY NOTE ON COOPERATION

Background

Wireless networks have witnessed a tremendous upsurge in recent years; this is mainly attributed to a lasting demand of high data rates anywhere and at anytime, which has been partially realized by a variety of commercially viable voice and data oriented applications. Traditionally, a centralized network infrastructure, such as GSM, is deployed by service providers; this approach worked fine in the past but commences to exhibit drawbacks, such as high cost, high power consumption and limited throughput.

An extreme alternative are ad hoc networks, where packets are forwarded in a multihop fashion. In such networks, users cooperate to relay and process each other's information. Notwithstanding their low cost, rapid deployment and self-organization capabilities, ad hoc networks face QoS, security and scalability problems. Consequently, standalone ad hoc networks are not promising for service commercialization. Indeed, business models for real world deployments are fairly complicated, having prevented a commercially viable deployment of pure ad hoc networks to date.

A natural hybrid approach is to beneficially fuse both of the above wireless paradigms in order to construct a single network with high flexibility and improved network performance. In such a network, a centralized base station (BS) or access point (AP) communicates directly with some users or fixed low-cost relaying stations, which in turn cooperatively relay information in an ad hoc fashion to other users in connectivity range. In the cellular case, such networks are typically referred to as *multihop cellular networks (MCNs)* as introduced by Lin & Hsu (2000). Subsequently, we will partially focus on cooperative MCNs, bearing in mind that the majority of exposed techniques and architectures are equally applicable to non-cellular networks.

MCNs can reduce the required number of BSs/APs and/or improve the throughput performance, whilst limiting path vulnerabilities typically encountered in multihop networks. They are potentially opening new business opportunities for network operators and service providers, allowing commercial service provisioning with broader coverage. However, for wide-area deployments of MCNs, appropriate architectures are needed allowing for cooperative multihop communication between similar wireless technologies and cooperative communication between different operators and service providers, as well as different wireless technologies.

We hence focus on possible deployment architectures for cooperative MCNs and the major technical challenges that are currently being resolved in real deployment scenarios from cooperation perspectives, such as routing, appropriate QoS metrics, authentication, and authorization to services' access, etc. We will, however, precede the architectural description of such networks by some basics needed to understand cooperative communication systems.

Some Useful Definitions

A large body of recent publications has led to numerous independent terminologies, some of which we wish to harmonize below (Dohler & Aghvami, 2007). These definitions relate to the cooperative system, the cooperative information flow, the nodes' behavior and the actual method of relaying.

Often occurring in the exposures of cooperation is the concept of *infrastructure*. An infrastructure – be it physical or logical – can:

- be available prior to deployment (e.g. cellular networks or WLANs); or
- emerge after deployment or simply remain unavailable (e.g. ad hoc networks).

The former is also referred to as infrastructure-based, whereas the latter as infrastructure-less. The infrastructure can be managed in the following fashions:

- centralized (e.g. cellular network); or
- decentralized (e.g. WLAN mesh network).

Note that one may have a decentralized infrastructure-based system (e.g. systems with decentralized radio resource management) or a centralized infrastructure-less system (e.g. clustering). Subsequently, we will mainly deal with centralized but hybrid infrastructure-based/less systems.

Another key-concept is related to the *information flow* from source to destination/target, which can be:

- point-to-point (traditional);
- point-to-multipoint (broadcast/multicast);
- multipoint-to-point (multiple access);
- multipoint-to-multipoint (general).

Generally, such *information flows can be realized* by means of:

- direct links (no relays between source and target);
- relaying links (at least one relay between source and target);
- relaying stages (clusters where information passes approx. the same time).

Each of the involved nodes in the network can have the following behavior:

- egoistic (no help);
- supportive (unidirectional help);
- cooperative (mutual help).

The *relaying process* itself can be:

- transparent (retransmission of originally received analogue signal); or
- regenerative (retransmission of digitally modified received signal).

The former is seemingly simple as it usually only involves some form of frequency translation and amplification of the received signal, whereas the latter comprises some baseband processing but is generally known to outperform transparent techniques.

An operator would clearly be interested in designing an infrastructure-based system, for which service and QoS provisioning can be guaranteed and influenced. Also, both financial and performance gains – if any – due to relaying and cooperation ought to be quantified, as well as the optimum choice of relaying techniques and technologies established.

Academic Milestone Contributions

The method of relaying, i.e. a canonical form of cooperation, has been introduced by van der Meulen (1971). A first rigorous information theoretical analysis of the relay channel has been exposed by Cover & el Gamal (1979). In these contributions, a source mobile terminal (MT) communicates with a target MT directly and via a relaying MT. The maximum achievable communication rate has been derived in dependency of various communication scenarios, which include the cases with and without feedback to either source MT or relaying MT, or both. The capacity of such a relaying configuration was shown to exceed the capacity of a simple direct link. It should be noted that the analysis was performed for Gaussian communication channels only; therefore, neither the wireless fading channel has been considered, nor have the power gains due to shorter relaying communication distances been explicitly incorporated into the analysis.

Only in the middle of the 90s, the idea of utilizing relaying to boost the capacity of infrastructure-based wireless networks revived, thereby leading to the concept of opportunity driven multiple access or ODMA (3GPP, 1999). Here, the power gains due to the shorter relaying links have been the main incentive to investigate such systems to reach MTs out of base station (BS) coverage. The emphasis of the study was its applicability to cellular systems, as well as a suitable protocol designs.

Interesting milestones into the above-mentioned theoretical studies have been the contributions by Sendonaris, Erkip & Aazhang (1998). In their study, a very simple but effective user cooperation protocol has been suggested to boost the uplink capacity and lower the uplink outage probability for a given rate. Moreover, they showed that cooperation can reduce the MT's power consumption. The designed protocol stipulates a MT to broadcast its data frame to the BS and to a spatially adjacent MT, which then re-transmits the frame to the BS. Such a protocol certainly yields a higher degree of diversity because the channels from both MTs to the BS can be considered uncorrelated. The simple cooperative protocol has been extended by the same authors to more sophisticated schemes, which can be found in their subsequent excellent publications.

The contributions by Laneman & Wornell (2000) are a conceptual and mathematical extension to Sendonaris, Erkip & Aazhang (1998), where energy-efficient multiple access protocols are suggested based on decode-and forward and amplify-and-forward relaying technologies. It has been shown that significant diversity and outage gains are achieved by deploying the relaying protocols when compared to the direct link. The case of distributed space-time coding has also been analyzed by Laneman in his PhD dissertation. In his thesis, information theoretical results for distributed single-input-single-output (SISO) channels with possible feedback have been utilized to design simple communication protocols taking into account systems with and without temporal diversity, as well as various forms of cooperation. He has demonstrated that cooperation yields full spatial diversity, which allows drastic transmit power savings at the same level of outage probability for a given communication rate.

Gupta & Kumar (2000) were the first to statistically analyze the information theoretically offered throughput for large scale relaying networks. They showed that if the M terminals and associated traffic distributions are random, then the capacity per terminal decreases in the order of $1 /\sqrt{(M \log M)}$. The analysis in (Gupta & Kumar, 2000) has been extended by the same authors to more general communication topologies, where the interested reader is referred to the landmark paper (Gupta & Kumar, 2003). Lately, a linear capacity scaling for a specific cooperative protocol has been exposed by Ozgur, Leveque & Tse (2007).

Whilst above milestone contributions concentrated on the simple relaying case, the concept of distributed cooperative relaying systems, also termed Virtual Antenna Arrays, with application to cellular networks has been introduced in February 2000 by Dohler (1999-2002). The generalization of the concept to distributed-MIMO multi-stage communication networks with application of distributed space-time codes has been introduced shortly after and consequently patented by M-VCE in June 2001 (Dohler, Said, Ghorashi & Aghvami, 2001).

Other excellent research in these areas has been performed thereafter, all of which led to the currently flourishing research area of cooperative wireless communication networks.

Industrial Motivation

The success of IP technologies jointly with the appearance of high data rate solutions at physical layer led to a rapid growth of telecommunications networks. For the wireless network, however, radio resources are limited (and expensive) and one cannot infinitely increase the network capacity. The availability of vacant bandwidth is not expected to increase significantly, and the gap will hence only widen.

To date, the only way to get around this is by controlling the transmission power and increasing the spatial reuse of frequencies by cell splitting/sectoring. These were the driving principles behind the design of cellular networks of the past (AMPS, GSM and also 3G). However, these methods incur huge installation and maintenance costs which explode in UMTS networks where micro-cells have a diameter of a few hundred meters. Further worsened by the high license fees, there is thus a burgeoning threat that high-quality wireless services may soon become an unaffordable luxury.

The need for a breakthrough in approaches to network dimensioning is hence evident. With the advance of recent academic developments as outlined above, cooperative relaying networks have proven to be a viable solution. Of particular commercial interest among operators are MCNs. Originally proposed by Lin & Hsu (2000), MCNs open the doors to a new paradigm of hybrid cellular and ad hoc networks. They rely on a set of BSs/APs connected to a backhaul network, as in conventional cellular networks, and on the mechanisms of multihop networks, in which the packets are relayed between peer wireless stations.

Numerous contributions have emerged ever since. To this end, aiming at fulfilling the requirement of IMT-Advanced, the WINNER project (https://www.ist-winner.org/) develops a new air interface that performs with scenarios ranging from Metropolitan Area to Local Area Networks. The WINNER interface inherently supports cooperative relaying features and provides cost-effective high data rate provisioning. Further, the economic evaluation of the solution showed that this can decrease the cost per bit transmitted by a factor of two to three (Esseling, Walke & Pabst, 2004).

Gunasekaran & Harmantzis (2005) present a comparative study of conventional point-to-multipoint (PMP) based IEEE 802.16 WiMAX with cooperative transmission-based mesh topology from an economic point of view. They show that – given reasonable assumptions on traffic, number of users, frequency allocation and number of hops – a mesh-based WiMAX solution is more affordable and advantageous. This is mainly due to lower wired backhaul costs and also the possibility of using lower antenna heights to serve as relays rather then conventional BSs.

From above, the expected coverage and throughput benefits of a cooperative relaying MCN approach with respect to conventional cellular networks are quantifiable and sufficiently large to attract industrial interest. From an economic view, the planning and optimization of BSs/APs together with the leasing costs of their locations could be reduced through MCNs. An unplanned deployment, however, gives justifiable gains only if the relay is about 10% of the BS cost and about 50-100% of the planning cost without relays (Timus, 2006). Furthermore, a potential increase in the wireless coverage due to cooperative relaying could be cost efficient for rural areas where the amount of users is lower and hence the income of the operator is limited.

Cooperative Relaying Techniques

From previously discussed building blocks, applied to the cooperative relaying case, we deem issues related to the wireless relaying channel, characterization of link and system capacity, as well as the various OSI layers of grand importance and hence briefly dwell on their state-of-the-art.

Characterization of Relaying Channels

Channel models are vital in the designing process of wireless systems, because they influence power budget dimensioning, transceiver design, performance behavior, etc. There are, however, only a few relaying channel measurements/models available and no explicit models, which cater for the distributed cooperative communication channel. We hence need to adapt known channel measurements and models to the distributed cooperative case, until explicit models will become available.

Channel models are composed in a multiplicative fashion of:

- pathloss (deterministic effect due to power loss over distance);
- shadowing (lognormally distributed random effect due to shadowed waves);
- fading (random effect due to phasor additions).

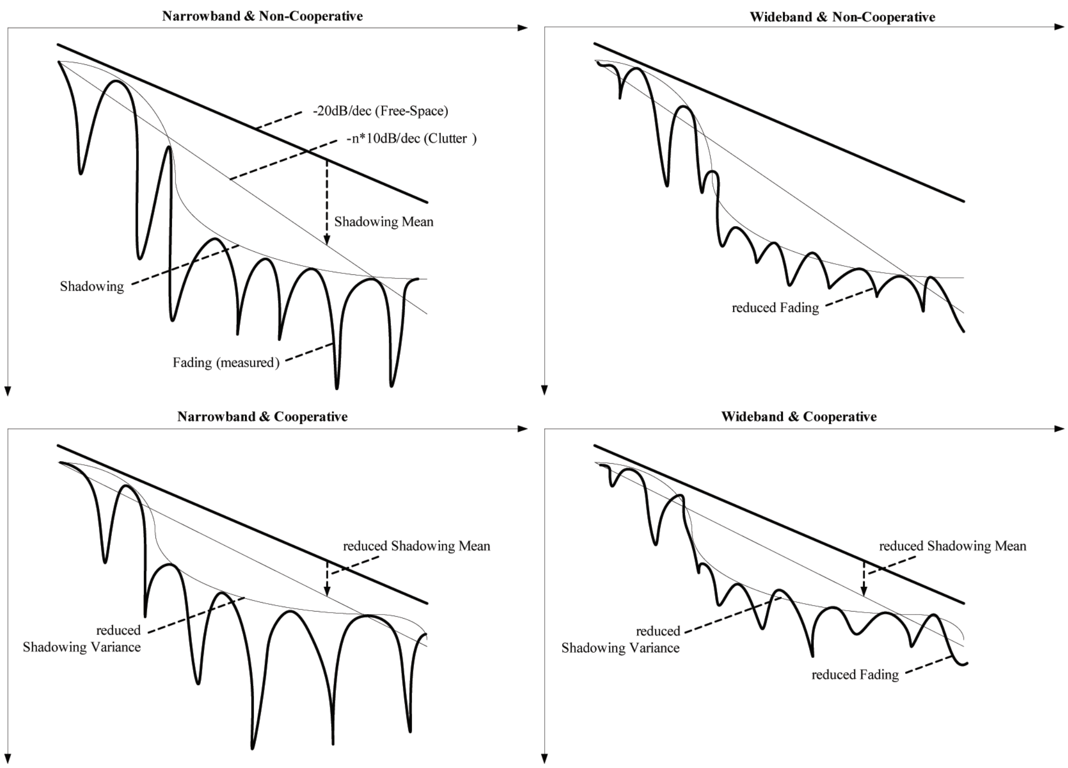
To characterize the above, we are particularly interested in the occurring pathloss coefficient, shadowing variance and shadowing correlation distance, fading statistics for each multipath component (MPC) and their correlation properties, and finally in the power delay profile with given delay spreads. Whilst some greater insights are given below for transparent and regenerative cooperative relaying channels, let us examine some general tendencies comparing narrowband/wideband cooperative/non-cooperative channel characteristics as observed by the destination terminal.

As exposed in Figure 1, compared to their narrowband counter-part, wideband communication systems manage to reduce the fading margin due to the additionally injected frequency diversity. Cooperative systems, in addition, have the advantage of reducing the shadowing margin due to a high spatial diversity. Such a reduction constitutes a serious advantage, as the performance of today's communication systems is dominated by the shadowing channel.

As for the *regenerative relaying channel*, the statistics of each individual cooperative relaying segment is of importance, thereby leading to point-to-point channel models. Since cooperative relaying systems are often composed of a cellular link from an elevated BS towards a relaying terminal as well as some non-elevated cooperative links among nodes, we will briefly summarize either characteristics (Konstantinou, Kang & Tzaras, 2007; Patel, Stüber & Pratt, 2006):

- pathloss coefficient n:
    - cellular links: $n = 2$ (LOS), $n = 2, \ldots, 4$ (nLOS);
    - cooperative links: $n = 2$ (LOS), $n = 4, \ldots, 6$ (nLOS);

Figure 1. Cooperative relaying channel power loss tendencies versus distance for narrow and wideband systems



- shadowing variance:
  - cellular links: 2, . . ., 6dB (LOS), 6, . . ., 18dB (nLOS);
  - cooperative links: 0, . . ., 2dB (LOS), 2, . . ., 6dB (nLOS);
- shadowing coherence distance:
  - cellular links: >100m (LOS), tens of meters (nLOS)
  - cooperative links: 40-80m (LOS), 20-40m (nLOS);
- first MPC fading statistics (other MPCs are Rayleigh distributed):
  - cellular links: Ricean $K = 2, \ldots, 10$ (LOS), Rayleigh (nLOS);
  - cooperative links: Ricean $K > 10$ (LOS), Rayleigh (nLOS);
- power delay profile:
  - cellular links: negative-exponential, clustered;
  - cooperative links: negative-exponential;
- root mean square (RMS) delay spread τ_{RMS}:
  - cellular links: depends on cell size, τ_{RMS} = 50ns, . . ., 4μs;
  - cooperative links: τ_{RMS} = 10ns, . . ., 40ns.

As for the *transparent relaying channel*, Laneman, Tse & Wornell (2004) have studied the statistical properties of a dual-hop amplify-and-forward cooperative relay channel. It has been shown that when the source-relay and relay-destination channels experience flat fading and their coefficients are independent complex Gaussian distributed, then the end-to-end channel (source-relay-destination) envelope is a modified Bessel function of zeroth order. It is interesting to point out that the temporal autocorrelation is a product of two first order Bessel functions. This leads to a faster decrease in correlation compared to the classic single relay channel, thereby complicated channel estimation procedures but aiding channel code performance.

Physical Layer Algorithms

At PHY layer, we distinguish three canonical relaying techniques, which can be used in conjunction with simple relaying or cooperative diversity relaying:

- amplify-and-forward;
- compress-and-forward; and
- decode-and-forward.

In the *amplify-and-forward* approach – being equivalent to *transparent relaying* – the cooperative relay down-converts the received analogue signal, amplifies it and up-converts it to another frequency band prior to re-transmitting it. The amplification requires some power constraints to be respected, where fixed or variable gain amplifications can be implemented. Note that this protocol suffers from severe performance losses at low signal-to-noise ratios (SNRs), because noise at the relay is also amplified. Furthermore, the analogue signal cannot be stored and hence requires immediate frequency translation; this implies two oscillators, two frequency bands and two fairly good filters – not necessarily making it a cheaper technology with respect to other relaying techniques. Apart from the below mentioned techniques, a feasible approach is to use quantization in order to store the analogue signal and then forward it in the same band in a TDMA fashion; see e.g. Djeumou, Lasaulce & Klein (2007).

The *compress-and-forward* approach is an extension of the amplify-and-forward method, where the analogue signal is sampled, quantized, compressed and re-transmitted. The advantage of doing so is to be able to temporarily store the signal or to relay it using a different communication standard. For instance, a 3G terminal could relay its received signal in compressed form via Bluetooth to adjacent terminals.

Finally, the *decode-and-forward* approach decodes the received signal and re-encodes it with a potentially different codebook prior to re-transmission. This clearly adds some complexity but at low SNR it exhibits a better performance than the amplify-and-forward approach. However, when the source-relay link is bad, this leads to a bottleneck for the transmission system since the relay is assumed to decode correctly the source message. Relay selection procedures are hence needed to overcome this problem and to increase the protocol's diversity order (Laneman & Wornell, 2003). Information theoretically, such a processing permits to adapt the relaying rate to the relay-destination capacity.

The requirement of two frequency bands and the inability to store the relayed signal makes, in our opinion, the amplify-and-forward a less likely deployment candidate when compared to the decode-and-forward protocol. We will hence concentrate on the latter, for which repetition based, channel code based, and space-time code based relaying methods are available. The first method repeats the received codeword (known to be sub-optimum from a code design point of view); the second method relays some parity information; and the third method constructs a space-time codeword between the source (s) and relaying (r) partners, thereby creating a distributed multiple-input multiple output (MIMO) antenna array with obvious performance gains (Dohler, 2003; Laneman & Wornell, 2003).

Repetition and channel code based methods require only a fairly loose synchronization at frame level between source and relay terminals, whereas the space-time code based relaying method requires a fairly tight synchronization at symbol level. This has lately been relaxed with the design of synchronization-robust space-time codes (Li & Xia, 2005).

Medium Access Control Mechanisms

Conflicts occur when more than one wireless link is active in a system. These conflicts are managed by the medium access control (MAC), which chooses:

- resources, i.e. which resources a link may use (e.g. specific time-slot);
- duplex method, i.e. whether the same frequency or different; and
- contention protocol, i.e. how each link gets access to the wireless medium.

Resources can usually be allocated using, e.g., time division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA), or orthogonal frequency division multiple access (OFDMA). The available duplex methods are time division duplex (TDD) and frequency division duplex (FDD). Protocols resolving contention are reservation-based MACs for typically centralized applications – in conjunction with, e.g., TDMA; and contention-based MACs for distributed applications – e.g. carrier sensing multiple access (CSMA).

Whilst the MAC is traditionally informed by the network layer about the next-hop destination, it needs to *select one or several suitable relay partner(s)* to facilitate cooperation. Several such protocols, based on different underlying assumptions and design goals, have e.g. been proposed by Ahmed, Ibars, del Coso & Mohammed (2007); Chou, Yang, & Wang, (2007); Jakllari, Krishnamurthy, Faloutsos, Krishnamurthy & Ercetin (2006); Librino, Levorato & Zorzi (2007); Liu, Tao, Narayanan, Korakis & Panwar (2007); Beres & Adve (2008); Michalopoulos & Karagiannidis (2008).

Since the relay channel is an additional traffic channel, the choice of relaying mechanism will influence the *multiple access protocol.* For instance, amplify-and-forward approaches require FDMA to be implemented at the relay because it is difficult to temporally store the analog signal, whereas the other two approaches also allow for TDMA.

The TDMA mode is generally realized by means of two phases. In the first phase, the source broadcasts information to the destination and the relay(s). In the second one, the relay(s) transmit(s) the information towards the destination. At MAC, this can be implemented using an *orthogonal as well as non-orthogonal mode*. For the orthogonal mode, the source does either not transmit in the second phase which reduces interference at the receiver side (Laneman, Tse & Wornell, 2004) or uses entirely orthogonal space-time codes (Dohler, 2003). For the non-orthogonal mode, the source also transmits in the second phase, which is known to increase the rate (Azarian, el Gamal & Schniter, 2005). Several works studied different versions of the two orthogonal and non-orthogonal modes. Their performance is compared using the diversity-multiplexing trade-off (Zheng & Tse, 2003) introduced for MIMO systems. It is shown in general that the non-orthogonal mode outperforms the orthogonal one, because, for the same diversity order, they achieve higher rates (Zheng & Tse, 2003). This has also been extended to broadcast and multicast channels (Azarian, el Gamal & Schniter, 2005).

To facilitate a cooperative MAC from an implementation point of view, two cases need to be distinguished: the *homogenous MAC* cooperation, where one distinct MAC layer is present in the system; and the *heterogeneous MAC*, where MAC protocols from different systems are used for cooperation.

Cooperation using a *homogenous MAC* takes advantage of the inherent properties of the wireless medium, its shared nature as well as the broadcast support of wireless transmissions. In practice, the conventional wireless systems are designed such that any unicast communication involves the two concerned parties only, i.e. the sender and the receiver. Therefore, existing MAC protocols ignore any overheard information from neighboring nodes that are not involved in the transmission. In a cooperative scenario, this situation leads to a multitude of retransmission and therefore bandwidth waste.

In order to counteract this waste and also improve the system reliability, new wireless medium access control solutions enforce additional cooperative mechanisms at the neighboring nodes, which can act as relays to improve the transmission reliability. In such a case, we consider three entities: the source, the destination and the relay. The source transmits first its MAC packet data unit (PDU). If the destination successfully receives this PDU, it sends an acknowledgement which will be overheard by both the relay and the source. In the case where the destination does not receive the PDU correctly but the relay node does, the latter transmits the PDU to the destination. If both the destination and the relay fail, the packet gets retransmitted by the source node.

Several practical solutions based on the suggested scheme with some minor variations are proposed in the literature. For instance, Azarian, el Gamal & Schniter (2005) proposed a new MAC protocol called CoopMAC which is based on the IEEE 802.11 distributed coordination function (DCF). Another proposal has been put forward in the standardization group IEEE 802.15.

In the case of a *heterogeneous MAC*, we consider the co-existence of several MACs in the system, a configuration which will occur more often in future beyond 3rd generation (B3G) and 4th generation (4G) systems. The cooperative system must take profit of this diversity to improve the effectiveness of the network and shall enable the inter-working between the different solutions. It can work either in handover based mode such that it triggers the hand off between two MAC technologies using a predefined criterion like signal strength, or in a complementary fashion, i.e. the traffic is divided over all the existing links. Cooperative solution in this context did usually not imply any specific modification at the adjacent MACs; it is basically managed at L2.5 in order to ensure the backward compatibility with existing system. Many proposals have been made to handle cooperation issues in heterogeneous MAC environments; for instance, IEEE 802.21 or the unlicensed mobile access (UMA), as well as I-WLAN.

Research on cooperation mechanisms at MAC layer should also ensure that no user misbehaves. For example, in the IEEE 802.11 DCF, all participating nodes adhere to the backoff protocol to ensure – in the absence of hidden nodes – a fair share of the bandwidth for each node. A selfish node might want to obtain more than its fair share of the channel bandwidth by selecting smaller backoff values or using a different retransmission strategy, such as not to double the contention window value after a collision (Kyasanur & Vaidya, 2003). Such a selfish behavior seriously degrades the throughput of the fair/no-selfish nodes. To deal with this issue, protocols where changes to the backoff calculation are sought. In Kyasanur & Vaidya (2003), the authors propose some modifications to the IEEE 802.11 DCF with the supposition of the presence of a trusted base station that can identify sender misbehaviors.

Network Layer Protocols

Cooperation from a network viewpoint concerns the cooperation mechanisms between network elements for traffic forwarding. More specifically, it is about the design of an efficient routing protocol that enables effective network resource management. Interestingly, from the higher level perspectives, the wireless network is represented as a set of wireless nodes that attempt to increase the system's quality of service

(QoS) via cooperation. Therefore, the problem to alleviate at the routing level considering a multihop path is how to select the best cascaded cooperative relay set from a source towards the destination. It is worth noting that an effective cooperation at network level implies the usage of cooperative transmission at both MAC and PHY layers.

We find in the literature numerous protocols that deal with the proper selection of next hop relays as well as multihop paths in a wireless environment. However, only a few routing protocols exist that really consider the existence of cooperative terminals along the route.

Bletsas, Khisti, Reed & Lippman (2006) advocate the use of opportunistic relaying as a practical scheme for cooperative solutions. A distributed path selection mechanism is proposed where the best relay is selected by the source using instantaneous wireless channel conditions, i.e. signal-to-interference-and-noise ratio (SINR) measurements, and then used to realize the cooperation between the source and the destination. The simplicity of the solution facilitates the coordination between the cooperative entities and bounds the overall signaling overhead. Adam, Bettstetter & Senouci (2008) propose two refinements: (i) 'relay selection on demand' where relays are only selected if required by the destination and (ii) 'early retreat' where each potential relay assesses the channel state and decides whether to participate in the relay selection process or not.

Biswas & Morris (2005) combine both cross-layer optimization and spatial diversity by investigating the performance of a link/network layer diversity routing protocol. The process of packet delivery is as follows: iteratively, at each hop and for each packet, a 'candidate forwarder' is selected by the source node from its one hop neighbor nodes and prioritized based on their proximity, in terms of number of hops to the destination. Therefore, the node with the highest priority will relay the received packet, whereas the other candidate forwarders transmit only the unacknowledged packets. Such an approach was shown to outperform traditional routing, typically increasing the overall throughput by a factor of two.

Jerbi, Senouci, Ghamri & Beylot (2008) propose a self-organizing mechanism to emulate a geo-localized virtual infrastructure (GVI). This latter is emulated by a bounded-size subset of cooperative vehicles currently populating the geographic region solving by the way the infrastructure dependence problem of some existing dissemination protocols.

Finally, w.r.t. Kim & Bohacek (2005), the essence of this contribution led to the design and the implementation of the best-select protocol (BSP), which generalizes single-path routing with sets of nodes substituting the concept of a single node relay. Consequently, the data are transferred from a given relay-set towards another relay-set. The channel gain information obtained through message exchange between relay-sets is utilized to select the best node as the relay to transmit the data to the next relay-set. The process is reiterated until the destination is reached.

As discussed in the previous section, it is important to study the node behavior in the case of infrastructure-less ad hoc networks. In fact, in such networks, where no centralized entity exists, a malicious or self-interested user can misbehave and does not cooperate. A malicious user could inject false routing messages into the network in order to break the cooperative paradigm. However, a self-interested user does not intend to directly damage the overall functioning, but to save its own resources. A user's selfishness is comprehensible as it is often requires to forward packets for the benefit of others, consuming precious resources that they want to save for their own communication. The basic network functions subject to selfishness are broadcasting and routing.

Current approaches to counteract such behavior and enforce cooperation at network layer can be broadly classified into two categories:

- pricing or credit based schemes; and
- reputation based schemes (Conti, Gregori & Maselli, 2004) .

Credit-based schemes consider packet forwarding as a market model where nodes providing a service are remunerated, whilst nodes receiving a service are charged. Hence, if a node wants to send its own packets, it must forward packets for the benefit of others. However, these schemes require tamper-resistant hardware (Buttyan & Hubaux, 2003) or infrastructure-dependent credit clearance systems (Zhong, Chen & Yang, 2003) that other nodes can trust.

Reputation-based schemes discourage misbehavior by estimating the nodes reputation and punishing nodes with bad behavior (Buchegger & le Boudec, 2002; Michiardi & Molva, 2002). The scheme requires each node to rate every other node with which it communicates based on the service received or on observing the behavior of neighbors by listening to communications in the same transmission range. According to the collected information, the reputation system maintains a value for each observed node that represents a reputation of its behavior. The reputation mechanism allows avoiding sending packets through misbehaving nodes.

COOPERATIVE RELAYING ARCHITECTURES

In this section, we attempt to show to which systems and architectural designs above outlined cooperative techniques and protocols are currently applied. We will briefly discuss the need to distinguish homogenous and heterogeneous approaches, after which we will discuss each in some details.

Homogeneous vs. Heterogeneous Architectures

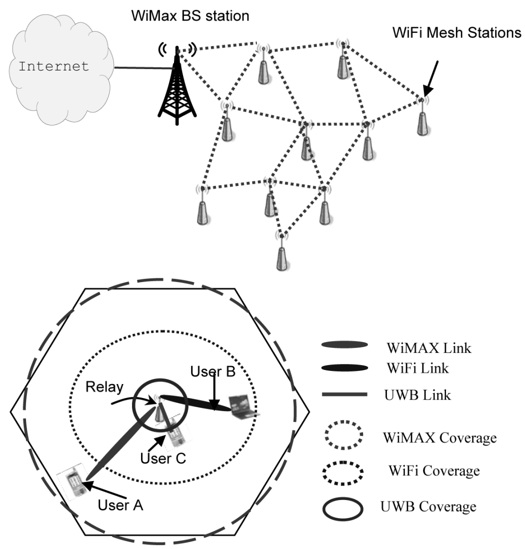
After having described the limitations encountered with conventional networks and motivating the use of cooperative systems as well as having dwelled on related state-of-the-art developments, we will review several proposals that describe possible realizations of cooperative multihop cellular networks.

Similar to the MAC layer, a classification ought also to be made on system architecture level based on the relaying technology used to facilitate the multihop communication. If the BSs/APs employ the same technology as the relay stations, e.g. both WLAN, we will refer to *homogeneous MCNs*. If they adopt a different technology, e.g. WiMax at the BS and WiFi and/or UWB for relaying (multi-mode relays are possible), we will refer to *heterogeneous MCNs*. This has been exemplified in Figure 2. Note that the BS shall handle all communication technologies used in the MCN.

Such a deployment would involve a repartition of intelligence and functionalities between the BSs and fixed relay stations, where the latter ensure the following functionalities:

- authentication, authorization and registration closer to the BS;
- topology discovery and update of routing table and traffic forwarding;
- resource scheduling QoS parameters establishment;
- managing user mobility and handover.

Figure 2. Deployment architectures of heterogeneous MCNs



Homogeneous Cooperative Architectures

By advocating a homogeneous design, MCNs extend seamlessly the connectivity provided by the underlying system without further modifications at the user terminal's side. A mobile node can hence benefit from and access to network services independently from the presence of the relaying system. We shall subsequently discuss solutions based on IEEE 802.16j and 802.11s. It is worth mentioning that such solutions have been developed within the IST ROMANTIK project (www.ist-romantik.org) for UMTS networks. The personal network standardization efforts at the IEEE are also currently studying such approaches within TG IEEE 802.15.5.

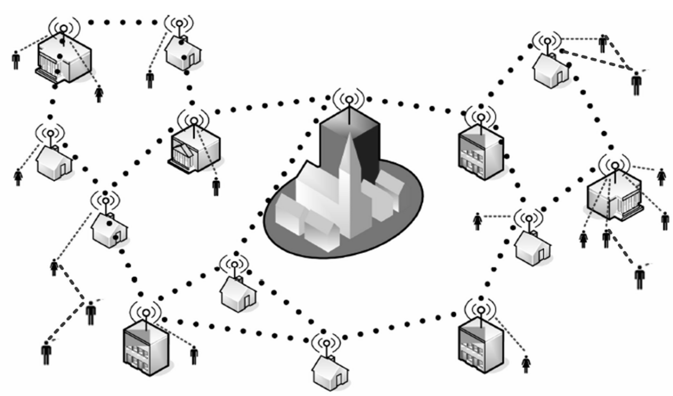
Relaying in Wireless Metropolitan Area Networks (WMAN, IEEE 802.16j). The IEEE 802.16j aims at defining a multihop solution for WMANs. To this end, they propose to expand the standard IEEE 802.16 model which currently only allows direct communication between the mobile station (MS) and BS; the multihop relaying is advocated using relaying stations (RS). Considerable complexity reduction is expected at the relay station compared to legacy IEEE 802.16 BSs. Cooperative transmission and relaying is one of the important features provided by the IEEE 802.16j standard.

The standard defines two types of relays: fixed and nomadic; these are expected to provide expandable connectivity in buildings and for special events. The nomadic relay will be carried by mobile vehicles, such as a buses, cars or trains.

The initial version of the IEEE 802.16 standard is expected at the end of 2008, addressing routing, resource allocation, security and handover issues. Multihop relaying will be central to the upcoming IEEE 802.16m standard to achieve the expected throughput, i.e. 1Gbit/s for nomadic and 100 Mbit/s for mobile users.

Relaying in Wireless Local Area Networks (WLAN, IEEE 802.11s). IEEE 802.11s aims at defining an extended service set (ESS) multihop mesh networking as an extension of the IEEE 802.11 MAC. The

Figure 3. Cooperative wireless community networks in 4G



objective is to define architecture and protocols that enable broadcast/multicast and unicast data transmission and delivery modes over multihop mesh topologies, as well as facilitating auto-configuration and radio-aware routing.

Wireless community networks (commercial, public and non-profit), as shown in Figure 3, are another example of cooperation at the network level.

Heterogeneous Cooperative Architectures

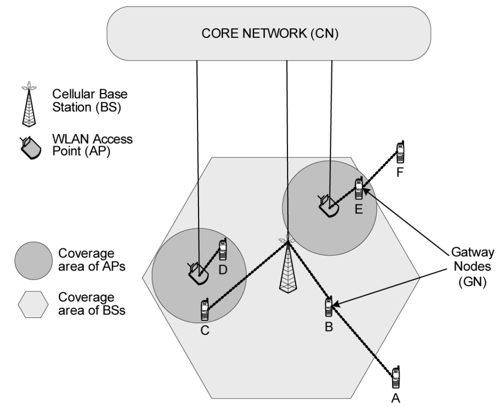
In heterogeneous MCNs, mobile devices need to be multi-mode supporting multiple air interfaces (cellular, Bluetooth, IEEE 802.11, IEEE 802.16, etc.) and different data rates. This, however, is an extremely complex task and leads to numerous challenges at all layers of the protocol stack.

Factors that influence the design of such architecture include multi-interface MSs, transmission power and co-channel interference management, topology and routing, mobility and handoff, load balance, interoperability, and QoS provisioning. However, the network layer is the most challenging since MSs can have various physical and MAC layer protocols that need to be considered in an integrated routing process. The selection of the end-to-end route for any connection may be based on the user's service level agreement (SLA) and depends on several metrics (number of hops, delay, throughput, signal strength, etc.). Furthermore, the network layer has to handle horizontal handoffs between BSs/APs of the same technology (cellular IP) and vertical handoffs between different technologies (Mobile IP) in a seamless manner.

In such environments, different types of connections can be established between any two MSs. When we consider that MSs could have two interfaces (e.g. WLAN/cellular), three different heterogeneous scenarios are possible as per Figure 4:

1. Source *A* uses the WLAN interface to connect to *B*, which can establish a connection to destination *C* through a cellular BS in infrastructure mode.
2. Source *B* and destination *D* use cellular and WLAN interfaces, respectively, and the corresponding BS and AP are connected through the CN.

Figure 4. Connection alternatives between two dual-mode MSs in heterogeneous MCNs



3. Source *A* uses its WLAN interface to connect to *B* that is connected to the BS, and this BS is connected through the CN to the AP that provides connectivity to the destination terminal *F* through *E*.

To facilitate communication, a number of architectures and hybrid routing protocols have been proposed in the literature; see, e.g., UCAN (Luo, Ramjee, Sinha, Li & Lu, 2003) or iCAR (Hu, Qiao, De & Tonguz, 2001). A detailed comparison of these integrated architectures is provided in (Cavalcanti, Cordeiro, Agrawal, Xie & Kumar, 2005).

Standardization

Ubiquitous cooperative protocols will likely find their way into standards and deployment with the advent of 4th generation (4G) systems. 4G is likely going to be composed of a heterogeneous plethora of seamlessly interconnected technologies (Fitzek & Katz, 2006). However, whilst cooperation at various layers between different systems has been in part discussed above, there are no finalized state-of-the-art standards available. Work only commenced; see, e.g., recent efforts of IEEE 802.16j, IEEE 802.21 and IEEE TG 802.15.5 as well as IEEE P1900 (www.ieeep1900.org) on reconfigurable networks facilitating cooperation.

CHALLENGES AND FUTURE TRENDS

Helping out other users in a cooperative fashion has its price – mainly, many unsolved problems in the area of routing, mobility management, authentication, incentive schemes and thus business modeling still prevail. In this section, we will dwell on their challenges and future trends.

Cooperative Relaying & Routing

Routing in cooperative MCNs utilizes additional resources available at the relays (which can be the user terminals). The objective is clearly to increase network radio coverage and optimize the utilization of shared network resources, i.e. it shifts a part of the processing and traffic load from the BSs to the relays. Therefore, routing needs to discover the integrated topology and find the best possible route.

Routing in cooperative MCNs may be simplified when the centralized part of the network has some control on the forwarding operations and is hence able to enforce cooperation policies. The centralized control in MCNs enhances the scalability of the entire system and dramatically improves self-x abilities. However, all these advantages come with signaling overheads; therefore, the trade-off between the overhead and route optimality needs to be considered.

A quantification of the increased network coverage by means of cooperative routing techniques remains an open question. Furthermore, the effect of egoistic relays on the limitation of the multihop route length between source and destination has not yet been considered.

Within a traditional network, networking operations are under the control of the operator. This is no longer the case with MCNs. Relay user nodes can easily disrupt forwarding operations for numerous reasons, such as:

- selfishness;
- temporary resource constraints;
- malicious purpose (intentional packet drops);
- mobility (radio link breaks).

The more hops a node is located from the BS/AP, the greater the probability of experiencing such disruptions. This gives an upper limit on the route length and also the relay infrastructure size, above which the proportion of data packets correctly received at the destination falls under an acceptable performance level.

We believe that in dynamic environments, such as MCNs, a route metric based solely on hop-count is not sufficient to maintain a good multihop connectivity between nodes and the BS/AP. To aid routing, there is a need to evaluate intermediary node behaviors and link qualities along the path, in order to quantify the expected cooperation level of the routes when nodes are located several hops away from the BS/AP. Several QoS metrics that reflect link quality can be used, such as ETX/WCETT (Draves, Padhye & Zill, 2004) or MIC (Yang, Wang & Kravets, 2005).

Mobility and Location Management

One of the important issues in providing ubiquitous communications is mobility management. In general, mobility management is a control plane that enables the network to locate a MS for call delivery and to maintain connectivity as the MS is moving to new service regions (mobility management also supports service discovery and vertical handoff; Xie, Kumar, Cavalcanti & Agrawal, 2006). The problem is acute in MCNs as the mobility of nodes affects the connectivity of not only the node that is moving but also of all other nodes maintaining links via it. The main objectives of mobility management architectures for homogeneous and heterogeneous wireless environments are to reduce the intra- and inter domain signaling load and handoff delay. Mobility support for heterogeneous networks has been addressed from different levels of the TCP/IP protocol stack. These include network level solutions, hiding the underlying wireless access technologies; link layer solutions, providing mobility-related features in the underlying radio systems; and cross-layer solutions for handoff management. Two general components of mobility management are handoff management and location management.

Several mobility management schemes attempt to reduce the packet loss incurred due to the node mobility between service regions. These include tunnel-based micro-mobility schemes like Mobile IP Regional registration (MIP-RR), Hierarchical Mobile-IP (HMIP), IDMP, etc., and routing-based micro-mobility schemes like Cellular IP (CIP), Hand-off Aware Wireless Access Internet Infrastructure (Hawaii), etc. (Akyildiz, Xie & Mohanty, 2004). While the micro-mobility solutions were proposed at network level for mobility of MSs between subnets of same domains for enabling transparent mobility for higher layers, the macro-mobility handled by Mobile IP tackle the mobility of users between different network domains. Mobile IP provides an effective solution for macro and global mobility management across homogeneous and heterogeneous systems.

Several cross-layer mobility management solutions were proposed in the context of heterogeneous wireless networks, and particularly MCNs with application to handoff management techniques. These include methods for low-latency MIP handoff and low-latency WLAN handoff. Seamless handoff techniques, including S-MIP, were also proposed for intelligent handoff management which provide a unique method of combining location tracking schemes and hierarchical MIP handoff schemes. The IEEE 802.21 standardization group is developing a MIH (media independent handover)-type cross-layer (layer-2 and layer-3) to enable mobility across heterogeneous networks by providing link layer intelligence and other related network information to upper layers to optimize handovers between heterogeneous media.

To transition MCN from a vision to reality requires the presence of efficient mobility management techniques which provides seamless connectivity with near-zero latency for the best possible user experience.

Security and Cooperation

As MCNs continue to grow and as their access is available for any wirelessly enabled device, cooperation between nodes should be guaranteed in order to assure the correct service provision. Hence, it should be ensured that only authorized users are granted network's access. We mainly notice two types of attacks in MCN environments: i) external attacks, where the attackers do not participate in the network, however they could carry out some attacks and malicious acts impacting the network and services performance, and ii) internal attacks, where the attackers participate in the network and have legitimate service access, however they penalize the network performance through malicious and non cooperative acts.

Prevention Against External Attacks. Indeed, authentication and access control are important counter-attack measures in MCN deployments, allowing only authorized clients to be connected and preventing external attackers to sneak into the network disrupting the normal cooperative operation or service provisioning. A simple solution to carry out authentication in MCNs is to employ an authentication key shared by all nodes in the network. Although this mechanism is considered as a *plug and play* solution and does not require the communication with centralized network entities, it is limited to closed scenarios of small number of participants in limited environments and belonging to the same provider. In addition, this shared secret authentication has two main pitfalls. Firstly, an attacker only needs to compromise one node to break the security of the system. Secondly, mobile nodes do not usually belong to the same community, which leads to a difficulty in installing/pre-configuring the shared keys. A challenge for wide scale commercial deployment of MCNs is to design authentication mechanisms for the more vulnerable yet more resource-constrained environment of MCNs. In most commercial deployments of WLANs, authentication and access control is mostly provided through employing IEEE 802.11i (IEEE 802.11i, 2004) authentication in which a centralized server is in place. In the context of MCNs, the challenge for applying the 802.11i approach mainly concerns the multihop characteristics and the hybrid infrastructure-based/less architecture. Hence, the 802.11i authentication model should be adapted to such environment through mainly considering two issues: i) introducing distributed authentication mechanisms, and ii) ensuring cooperation between nodes to support the hybrid architecture.

A possible approach for distributed authentication is the continuous discovery and mutual authentication between neighbors, whether they are mobile clients or fixed APs/BSs. Nevertheless, if mobile nodes move back to the range of previous authenticated neighbors or fixed nodes, it is necessary to perform re-authentication in order to prevent an adversary from taking advantage of the gap between the last security association and the current security association with the old neighbor. An approach adapting the 802.11i authentication model to multihop communication environments is presented by Moustafa, Bourdon & Gourhant (2006), proposing an extended forwarding capability to 802.11i and allowing mobile node authentication with the authentication server in a multihop fashion. The notion of friend nodes is introduced allowing each mobile node to initiate the authentication process through a selected node in its proximity, which plays the role of an auxiliary authenticator and forwards securely the authentication requests to the authentication server. Friend nodes are chosen to be trusted and cooperating nodes. This approach is suitable to the hybrid infrastructure-based/less architecture in MCNs, allowing mobile nodes beyond the APs/BSs coverage zone to get authenticated in a cooperative manner, through communicating with the authentication server at the infrastructure while passing by cooperative nodes (friend nodes). In addition, this approach allows authentication keys storage among intermediate (friend) nodes which optimizes the re-authentication process in case of roaming. Another possibility to facilitate multihop authentication is to employ a Protocol for carrying Authentication and Network Access or PANA (Forsberg, Ohba, Patil, Tschofenig, & Yegin, 2007). PANA allows the encapsulation of the used authentication protocol messages and their routing to the authentication server. The advantage of PANA mainly lies in its independence of the wireless media, and thus it is suitable for future cooperative MCNs having heterogeneous deployments and operator co-existence. However, PANA necessitates the existence of a routing infrastructure, which is a technical challenge for MCNs as previously outlined.

Prevention Against Internal Attacks. Although authentication and access control can reinforce cooperation through prevention against external attackers, internal attackers could always exist even in the presence of effective authentication and access control mechanisms. Internal attackers are nodes that are authenticated and authorized to participate in the network; however, they can be harmful nodes causing network and service performance degradation mainly through non cooperative behaviors (selfishness, greediness, and Denial-of-Services or DoS). Hence, there is a need for complementary mechanisms to authentication and access control. Nodes may behave selfishly by not forwarding packets for others in order to save power, bandwidth or just because of security and privacy concerns. Watchdog (Marti, Giuli, Lai & Baker, 2000), CONFIDANT (Buchegger & le Boudec, 2002) and Catch (Mahajan, Rodrig, Wetherall & Zahorjan, 2005) are three approaches developed to detect selfishness and enforce distributed cooperation and are suitable for MCNs multihop environment. Watchdog is based on monitoring neighbors to identify a misbehaving node that does not cooperate during data transmission. However, CONFIDANT and Catch incorporate an additional punishment mechanism making misbehavior unattractive through isolating misbehaving nodes. On the other hand, nodes may behave greedily in consuming channel and bandwidth for its own benefits at the expense of the other users. The DOMINO mechanism (Raya, Hubaux & Aad, 2004) solves the greedy sender problem in 802.11 WLANs with a possible extension to multihop wireless networks and MCNs. Internal attackers may also cause DoS through either faked messages injection or messages replay. DoS is a challenging problem greatly impacting cooperation, however it could be partially resolved through effective authentication of messages and messages' sources.

Business Models

MCNs require special accounting mechanisms and tailored billing systems, where appropriate business models should exist while considering the benefits of mobile users, network operators, and service providers. Business models should take into account the cooperation between different operators and service providers, which is a liable fact in future MCN deployment. Consequently, inter-domain accounting is required to assure services' access continuity. Billing in this context is expected to use gathered accounting information for each client, provided that a trust relationship exists between different operators and service providers.

Moreover, business models should take into account the cooperation between MCNs nodes. Mobile nodes should obtain credits for services' relaying, depending on their participation in the communication process, where nodes can be compensated (rewarded) according to their participation. In this context, payment mechanisms should be proposed for encouraging the cooperation between mobile nodes, where a sort of remuneration can be done for each participant according to his contribution. Another alternative is to let each node pay *cash traffic* for its own transfer and in turn gain *cash traffic* in order to forward packets for other nodes. The notion of *cash* could also be real money.

As a matter of opening a new business opportunity, business models should be rentable for telecom operators on one hand and affordable for wireless users on the other hand aiming to promoting services and attracting clients. Consequently, *paying access* models permitting different users privileges, according to the types of subscriptions, are the most appropriate ones. Privileged access to services in this context could include: secure communication, quality of connectivity, and different access rights to these services. In order to ensure the proper operation of the *paying access* models, the fulfillment of authentication and authorization to services' access is necessary. There are a number of possibilities to realize the *paying access* models; for example:

- Clients can go through the payment process each time they access the services. An o*n-use package* model can be applied in this case, through using pre-paid cards for instance. The advantage in this model is that payments are made according to the services' utilization. However, there is a need for complementary mechanisms allowing efficient management for clients' accounting information.
- A *pure package* (pay before use) business model, which could be associated to the clients' Internet subscription or telephone subscription and where the billing is monthly fixed whether the client uses the service or not. This model offers different privileges for clients according to their type of subscription, allowing the network operator/service provider to master the clients' access.
- A virtual operator model, in which the clients' access to different services is assured by service providers who do not own the deployed access network. On the other hand, the service providers are responsible of managing accounting and billing of mobile clients. This model permits the

integration between different service providers and the operators owning the access networks and can simplify managing the accounting information of mobile clients.

We believe that at least one of above models will yield non-negligible gains for operators and service providers.

CONCLUSION

As we had outlined in Dohler, Meddour, Senouci & Saadani (2008, p. 14), "*cooperation is not a natural characteristics attributed to human beings. The typical human horizon is focused on short-term gains, which might be due to our instinct-driven subconscious occupying a grander importance than we dare to admit (Gray, 2002). Cooperating with other individuals or entities, however, usually means that short-term losses may translate into long-term gains. Any cooperative technology depending solely on human decisions is hence a priori doomed to fail; history has shown this on numerous occasions. By contrast, if machines only have access to some decision making engines, cooperative schemes become viable communication techniques and are likely to occupy an important place in the technological landscape of the 21st century.*"

Above statement is corroborated by numerous previous attempts to commercialize networks based on cooperative techniques. The most prominent example is ad hoc networks, which have already been researched for some decades without having produced a single viable commercial product. The main reason in our opinion is twofold (Dohler, Meddour, Senouci & Saadani, 2008): First, the design degrees of freedom have turned out to be too large to reach commercialization; i.e., a psychological barrier prevailed at the manufacturer and service provider side, which prevented the deployment of such technology that had not even been fully mastered for much simpler cellular systems. Second, the data relaying process required users to give away battery power and bandwidth, and possibly jeopardize the security of their own data, with no obvious instantaneous gains; i.e., a psychological barrier prevailed at the user side, which has turned out to be hardest to break. Other examples of cooperative relaying technologies to have failed are the UMTS Concept Group Epsilon, which proposed ODMA as a potential 3rd generation (3G) candidate solution (3GPP, 1999), and Ricochet® (www.ricochet.net), a US company which was well ahead of its time by rolling-out a broadband wireless network throughout major US cities more than 10 years ago without this technology ever having really taken off.

Very few technologies, no matter how compelling, were successful – mainly because they appeared at the right time, at the right place, at the right pace, and supported by the right team.

For offered services, where the end-user had the last word, many failed technologies were simply either far ahead of time (i.e. the user was psychologically not prepared to accept the new technology and got around it by using another – possibly worse – technology) or lagged behind time (i.e. the user was already saturated with similar technologies and saw no reason – particularly for incremental gains – to change technologies).

In our opinion, cooperative techniques will likely survive in scenarios which are independent of users but only depend on machines or operator-programmed decision engines. Examples of the former are machine-to-machine applications, such as wireless sensor networks, where cooperation benefits data reliability, energy savings, network longevity, etc (Dohler, Gkelias & Aghvami, 2006). An example of the latter are the architectures exposed in this chapter, i.e. the cooperative multihop cellular network architecture.

These cooperative MCNs are clearly emerging as a promising new technology, benefiting from both cellular and ad hoc networks technologies whilst alleviating some critical problems in these networks. We have shown that MCNs seem attractive in opening new business opportunity for network operators and service providers, enabling commercial service provisioning with broad coverage on one hand and seamless mobility for mobile clients with improved overall QoS on the other hand. We exposed the motivation and importance of deploying cooperative MCNs, highlighting some appropriate deployment architectures. In addition, we reviewed some important challenges for a real-world deployment of such networks. These challenges are interesting for operators and providers, enabling the feasibility study of cooperative deployment taking into consideration the design-cost principle.

We have shown that homogeneous and heterogeneous solutions MCN architectures prevail. These are currently being standardized in various standardization groups of the IEEE. We have explained why, in contrast to pure ad hoc routing protocols, routing in MCNs may be simplified due to the centralized part of the network having some control on routing operations. This enhances network scalability and significantly improves the self-organization abilities of the system.

We presented mobility and smart roaming solutions, which are applicable to MCNs. It has been emphasized that cross-layer solutions are vital in ensuring reliable mobility solutions. We have also alluded to the gamut of existing routing metrics, such as expected transmission count, expected transmission time, etc, and discussed their merits as well as short-comings.

Security and cooperation are two important issues that need to be resolved. Authentication and access control mechanisms should be in place, taking into consideration the dynamic and not fully centralized nature of cooperative networks. It is important to be mindful of the authentication overhead as wireless mobile users are often thin-clients with limited resources. Also, unacceptable authentication delay can impact the services' continuity. Complementary mechanisms to authentication and access control should exist as well, in order to assure the cooperative behavior and prevent against internal attackers.

From a commercial deployment perspective, business models should take into account the fact that cooperative MCNs can be managed by more than one operator/provider and hence allow for such co-existence. Special accounting mechanisms and tailored billing systems are needed. Business models should have mutual benefit in the sense of being rentable for operators and attractive for mobile clients (nodes), where they can integrate some mechanisms inciting the nodes cooperation.

The momentum of research into cooperative technologies in the context of incumbent and emerging cellular and local area networks is very large and it commences finding its input into various standardization bodies. It is hence safe to assume that this technology – in one way or another – will be part of our future wireless arena.

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GLOSSARY

3G: 3rd Generation (Mobile System)
3GPP: 3rd Generation Partnership Project
4G: 4th Generation (Mobile System)
APL: Application (Layer)
BS: Base Station
BSPL: Best-Select Protocol
CAPEX: Capital Expenditure
CDMA: Code Division Multiple Access (Protocol)
CSMA: Carrier Sensing Multiple Access (Protocol)
DCF: Distributed Coordination Function
FDD: Frequency Division Duplex
FDMA: Frequency Division Multiple Access (Protocol)
GSM: Global System for Mobile Communications
ITS: Intelligent Transportation System
ITU: International Telecommunications Union

MAC: Medium Access Control
MHz: Mega Hertz
MIMO: Multiple-Input-Multiple-Output
MT: Mobile Terminal
M-VCE: Mobile Virtual Centre of Excellence
NTW: Network (Layer)
ODMA: Opportunity Driven Multiple Access
OFDMA: Orthogonal Frequency Division Multiple Access (Protocol)
OPEX: Operational Expenditure
OSI: Open Systems Interconnection (Reference Model)
PDU: Packet Data Unit
PHY: Physical (Layer)
QoS: Quality-of-Service
R&D: Research and Development
RRM: Radio Resource Management
SISO: Single-Input-Single-Output
SINR: Signal-to-Interference-and-Noise Ratio
SNR: Signal-to-Noise Ratio
TDD: Time Division Duplex
TDMA: Time Division Multiple Access (Protocol)
THz: Terra Hertz
TV: Television
UMA: Unlicensed Mobile Access
UMTS: Universal Mobile Telecommunications System
WLAN: Wireless Local Area Network
WRC: World Radio Conference
WSN: Wireless Sensor Networks