Reaching Network Ubiquity through a New Concept of Mobile Terminal

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Abstract

The concept of mobile system as we know it today is about to change. It is expected that by 2020 the networks become cooperative and users collaborate in the transmission of information to other devices. This new paradigm of mobile relaying implies a set of new challenges that the scientific community is currently addressing. This paper introduces this new paradigm for mobile communications as well as the main problems, possible solutions, the current state of technology and most appealing research trends.

Keywords: Mobile Relay, Next Generation Mobile Systems, 5G.

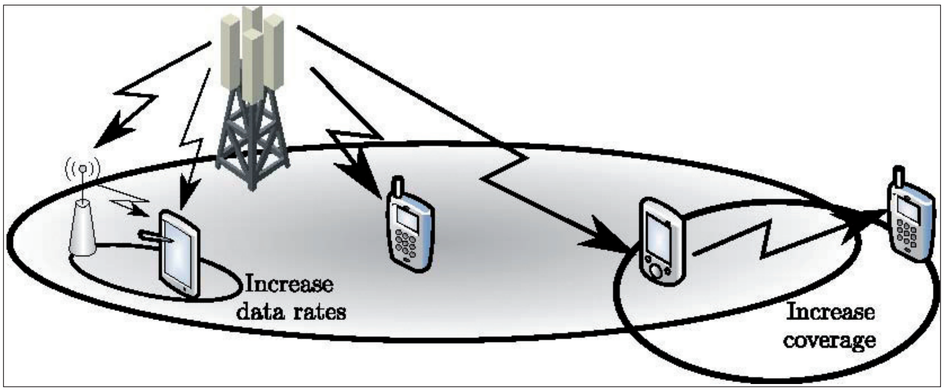
1. Introduction

Today, users are increasingly demanding higher data rate applications anywhere and anytime. In this new scenario, data rates offered by mobile operators must be similar or even higher than traditional Internet Service Providers (ISPs). With the purpose of addressing this market, the 3rd Generation Partnership Project (3GPP) started the standardization of the evolution of Universal Mobile Telecommunications System (UMTS), called Long Term Evolution (LTE).

LTE is the first step towards a new cellular system known as LTE-Advanced (LTE-A), which is expected to offer peak data rates of 1Gbps in Downlink (DL) and 500 Mbps in Uplink (UL) for low mobility users [1]. Novel techniques such as aggregation of multiple carriers, advanced Multiple Input Multiple Output (MIMO) with up to 8 data streams in DL and up to 4 data streams in UL, Coordinated Multi-point Transmission/Reception (CoMP) or relaying, suppose a disruptive evolution of the current cellular networks [2]. It is worth noting that, despite both LTE-A and Worldwide Interoperability for Microwave Access (WIMAX) 802.16m have been accepted by the International Telecommunications Union (ITU) as Fourth Generation (4G) mobile technologies, LTE-A system is considered to be the most predominant system around the world.

All these modifications are not only due to the need of higher data rates but also due to the lack of equity in data rates among User Equipments (UEs). Cell-edge users suffer performance degradation as the distance to the Base Station (BS) increases due mainly to propagation loss. Cellular operators tend to increase cell-edge throughput by increasing the number of deployed BSs at the expense of higher capital and operational expenditures. At the present time, and because of this dense deployment of BSs, there are severe problems related with inter-cell interference. To overcome this situation, a heterogeneous network comprising an additional set of pico, femto and relay nodes is under consideration within the 3GPP. These low power nodes are smart devices that help the BS to increase fairness, reduce power consumption and boost data rates.

This paper focuses on relaying as a means to ensure ubiquity in Quality of Experience (QoE). In Figure 1, a cooperative network composed of a set of Relay Nodes (RNs) is showed. To date, the international scientific community has focused on the fixed relays and recently the 3GPP has specified the functioning of this type of relay in Release 10 and 11 [3]. On the other hand, mobile relaying is cu-



■ **Figure 1.** *Cooperative network with fixed and mobile relays.*

rrently arising as the natural evolution of fixed relaying due to its higher flexibility and availability. Traditionally, mobile relaying concept has coined the use of high-speed vehicles, like trains, acting as BSs. However, this concept can be easily extended to the case where the UE becomes a Mobile Relay (MR).

If the relay is moving then new problems appear like Doppler effects and the need for radio resource management, selection of RNs and incentives for cooperation, among others. Another of the associated problems with the use of MR is that the UE spends its battery helping other UEs. Of course, the UE acting as MR could help in some specific scenarios and with certain incentives. This topic is of paramount importance and it is considered as one of the limiting factors in the cooperation of the UEs. UEs acting as MRs will help networks providers improve coverage and link performance. In return, they must be rewarded with lower service costs or better QoE.

This paper focuses on this new paradigm of mobile relaying and surveys its current state of the art. Section 2 presents the current status of standardization activities. Section 3 discusses the key issues on mobile relaying. The problems and solutions related to mobile relaying are described in Section 4. Finally, Section 5 discusses about future trends and the horizon of mobile relaying.

2. Current Status of Mobile Broadband Technologies

The 3GPP ended in December 2007 the standardization of the physical layer of LTE Release 8. This OFDM technology supports variable bandwidth so that users can be served in different frequency bands and make use of frequency diversity. Moreover, MIMO techniques are included to enhance user data rates [4]. In Release 9, a number of minor improvements were included mostly related to Home eNodes B (HeNBs). These femto-cells serve home or small office environments. In addition, some progress in Self-Organizing Networks (SONs) was made with the aim of easily planning and configuring the mobile network.

The standardization progressed in Release 10 with the study and development of the LTE-Advanced technology. This activity started after the circular letter sent by the ITU-R, for which all technologies that meet certain requirements would be considered as technologies of the International Mobile Telecommunications-Advanced (IMT-Advanced) family or 4G technologies. Moreover, some additional spectrum was identified by the ITU-R for these IMT-Advanced technologies, what motivated the 3GPP to meet the IMT-Advanced requirements through a further evolution of LTE Release 8 and 9.

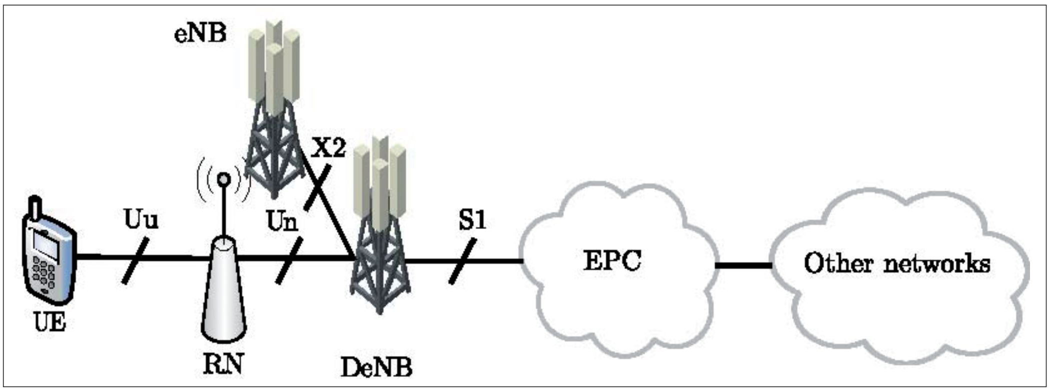
In order to achieve these requirements, the 3GPP focused on five major improvements, which constitutes the basics of LTE-Advanced Release 10 [5, 6]:

- Support of wider bandwidth, up to 100 MHz.
- Advanced MIMO techniques.
- Heterogeneous networks and enhance Inter-Cell Interference Coordination (eICIC).
- Fixed Relay.
- Coordinated Multi-Point transmission and reception (CoMP).

LTE-A is backward compatible with LTE Release 8 and 9. An LTE-A UE has reception and/or transmission capabilities in one or multiple frequency bands. On the other hand, an LTE UE can transmit or receive on only a single frequency band. A more detailed description of LTE and LTE-A can be found in several books such as [7, 8] or in various manuals [9].

Concerning relaying, it is worth noting that to date the 3GPP has mainly focused on fixed relays, which appeared first in Release 10 specifications. Only in the still-incomplete Release 11 one study group has initiated the analysis of a specific case of mobile relay in which a BS is located on high speed vehicles like trains or buses. The main challenges of this type of scenarios are the handover management and high Doppler frequency.

Figure 2 shows the general architecture of LTE-A with a fixed relay. The relay is wirelessly connected to a Donor eNB (DeNB) through the Un Interface (backhaul link). On



■ **Figure 2.** *General architecture of an LTE-Advanced system with relays.*

the other hand, UEs are connected to the relay through the Uu interface (access link).

If the access link shares the same carrier frequency as the backhaul link this is an in-band relay, being otherwise an out-band relay. In-band relaying entails higher radio resource management problems for the system as compared with out-band relaying. Moreover, two types of relays have been considered in Release 10 taking transparency into consideration:

- **Non-transparent.** This relay controls the cell in the same way as an eNB, that is to say, transmits its own synchronization channels, reference symbols, scheduling information, Hybrid Automatic ReQuest (HARQ) feedback and has its own Physical Cell ID. There are three types of non-transparent relays.

  - o Type 1. The relay is regarded as an in-band relay and there is a time division multiplexing between backhaul and access link.
  - o Type 1a. Different frequency carriers are used for backhaul and access link, i.e. out-band relaying.
  - o Type 1b. The backhaul and access link can operate simultaneously and in the same band thanks to adequate antenna isolation.

- **Transparent.** In this case the UE does not even realize that there is a relay, that is, the radio protocols terminate in the DeNB and not in the RN.

In order to allow in-band relaying without interferences, some mechanism must be used to share resources between the access link and the backhaul link in DL. As in Type 1b, an easy mechanism is to isolate the transmitter and the receiver so that the signals do not interference themselves. However, this is always not available. The 3GPP proposed that the RN can only receive data from the DeNB in the so-called Multicast/Broadcast over a Single Frequency Network (MBSFN) subframes being not able to transmit at the same time to the UEs in DL. The RN informs the UEs via Radio Resource Control (RRC) signalling when they should not expect any transmission from it. However, note that each UE expects to receive at least the Physical Data Control CHannel (PDCCH) in every subframe. Therefore, the RN has to transmit this information to the UE even in MBSFN subframes, and thus, does not listen to the PDCCH sent by the eNodeB. Therefore, a new control channel called R-PDCCH is needed in the backhaul link. This additional signalling overhead reduces the amount of resources available for data information. The R-PDCCH is sent in the fourth OFDM symbol of the first slot for DL assignments and in the last OFDM symbol in the second slot for UL grants.

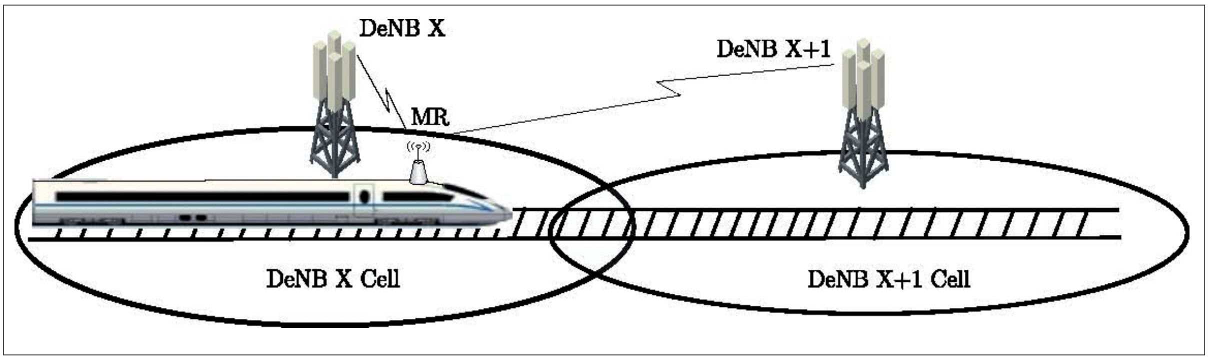
Concerning the UL, the isolation of the access and backhaul link is straightforward since the RN sends the UL grant scheduling to the UEs and, therefore, has full control over the transmission and reception of the UEs. On the other hand, the transmission resources of the Physical Uplink Control CHannel (PUCCH) sent by the RN are previously determined by higher layer signaling.

2.1. Technological roadmap

The standardization activity of the 3GPP concerning mobile relaying started by the end of December 2011 [10]. As depicted in Figure 3, the scenario under study consists of a relay node situated on a high speed train with the following features:

- Train velocity: 350 km/h.
- Known trajectory.
- High penetration losses of the radio signal through the shield carriages.
- UE on the trains are stationary or move at pedestrian speed.

Some open issues arise when addressing this scenario due to the high speed of the vehicle. First, this speed causes a severe Doppler effect and high penetration losses. Second, Handover (HO) failure rate may significantly increase hence degrading the received signal and increasing the battery power consumption of UEs. For instance, in a rural scenario in where the cell radius is around 577 m, the train speed provokes a HO event each 6 seconds. Therefore, it is the paramount importance the management of this type of fast HOs.



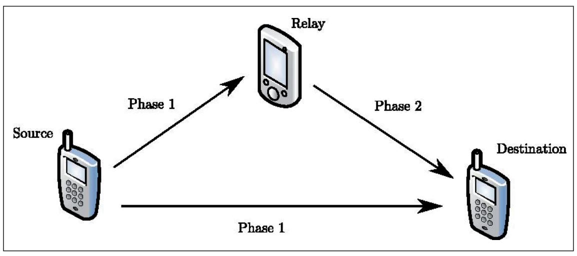
■ **Figure 3.** *Scenario under study based on a high public transportation.*

In order to solve these problems and improve the coverage within the train, one or several MRs can be mounted on the high speed train. These devices provide a wireless back-haul connection via a DeNB along the railway by an outer antenna and also wireless connectivity to the UE inside coaches by inner antennas. In addition, MR can have group mobility capabilities, so that the MR performs a group mobility HO procedure instead of individual HOs. Moreover, thanks to relaying, the transmit power is significantly reduced leading to important power savings.

3. Key Issues on Mobile Relaying

Cooperative relaying takes advantage of the broadcast nature of the medium by allowing nearby nodes that overhear the transmitted signal to make additional transmissions. It provides additional diversity against link outages such as fast fading or shadowing effects. To illustrate the basics of cooperative communications based on relays, Figure 4 shows the simplest topology with one source node, one relay node and one destination node. The transmission process comprises two phases. In phase 1, the source broadcasts a message to the destination and relay nodes. In Phase 2, the relay sends information to the destination (in different time slots or different orthogonal channels) and the destination combines the messages from the source and relay.

There are some open issues concerning mobile relaying. First, the source node has to define a criterion to choose the most appropriate relay node. This process is called relay selection. Second, it is also necessary to define how the relay node is going to forward the information, choosing the type of relay best-suited for the specific situation. Third, mobile relaying implies a waste of resource in the RN that must be recognized and compensated by the system. These incentives for cooperation must be also optimized.



■ **Figure 4.** *Basic relay scheme.*

3.1. Relay selection

There are several protocols proposed in the literature to choose the best RN. This selection is made by the network, although the current research trend points towards implementing these protocols autonomously. Some algorithms only consider the geographical position of RNs [11]. Others base their decision on the mean end-to-end Signal-to-Noise Ratio (SNR) [12]. Some strategies do not always use RNs and the source decides whether to employ the RN or not depending on the instantaneous values of the source-destination and source-relay channel gains. There are a plethora of Relay Selection (RS) algorithms that suppose a full knowledge of the Channel State Information (CSI). In [13], a cooperative protocol based on partial CSI at the source and the relays is proposed. The main objective of this scheme is to achieve higher bandwidth efficiency whereas guaranteeing the same diversity order as that of the conventional cooperative scheme. The argument of this protocol is that there is no need for relaying if the direct link channel is good enough.

In power-limited networks, the use of algorithms that tend to choose relays located as close as possible to the destination reduces the number of hops but usually requires that the transmitter node uses a large amount of power to reach the relay node, increasing the level of interference. In such case, it is necessary to find a trade-off between the necessity to limit the number of hops and the amount of interference generated. In this sense, [14] estimates this amount of interference based on the RS algorithm.

In general, interference signals transmitted from other cells degrade system performance and of course affect RN too. In [15], a RS scheme that takes into account interferences is proposed to tackle this problem.

3.2. Types of relays

Throughout the literature three relay protocols can be distinguished:

- **Amplify and forward (AF).** These RNs, also known as Layer 1 (L1) relays, amplify not only the interest signal but also the noise and the interference from other cells and forward it to the destination. This simple processing benefits cooperative wireless networks at high SNR. However, at low SNR performance is degraded because the noise component is also amplified. Therefore this scheme is not recommendable in high-interference environments.

- **Decode and forward (DF).** In this case, RNs first decode the received signal, and if it is correctly decoded then the re-encoded signal is forwarded to the destination node. Encoding/Decoding process prevents the retransmission and possible amplification of noise, but at the expense of introducing some latency and at the cost of extra processing. When the source-relay link is good enough, DF provides better performance than AF protocol. However when the link suffers from deep fading, the decoding could produce extra errors that propagate to the destination, resulting in a worse performance. Moreover, DF entails a large amount of computational burden at the RNs. Depending on which functions are included in the relay, RNs can be classified into Layer 2 (L2) relay and Layer 3 (L3) relays. L3 RNs can be considered as small BSs with less coverage that receive and forward IP packets.

- **Compress and forward (CF).** Also known as estimate-and-forward or quantize-and-forward; in this technique the RN compresses the signal received from the source and forwards it to the destination without any decoding. CF may mitigate some of the noise amplification effects by a proper choice of the quantizer or compressor. It has been shown that the performance of CF in terms of data rate is better than DF when the relay is close to the destination.

3.3. Incentives for cooperation

The majority of papers addressing relaying suppose that all nodes are willing to cooperate selflessly. However, nodes are often autonomous and aim to optimize their utility function, such as their data rates or transmitted power, hence minimizing their cooperation. Indeed, collaboration consumes resources like energy and computing power and does not provide immediate benefits. Therefore, nodes are not interested in cooperation without an incentive. Over the last decade, several techniques have been proposed to encourage cooperation and improve the efficiency of wireless networks using relaying.

One approach is to encourage cooperation through the dissemination of reputation information about each node. A node helps another node depending on its reputation. However, this approach is not always beneficial due to several reasons. First, there is room for possible misinterpretations of the nodes' behaviour. Second, node complexity will increase due to the others behavior monitoring. Finally, reputation messages must be propagated, what increases signalling overhead [16].

At the present time, and because of this dense deployment of BSs, there are severe problems related with inter-cell interference.

Another approach is to use a virtual currency that allows nodes to be remunerated for relaying. Nodes accumulate credit through cooperative behaviour and use this credit to purchase cooperation from other nodes [17]. Moreover, incentive mechanisms can discourage launching exhaustive requests because the nodes pay for relaying their packets. On the other hand, it can also be useful to operators that could give incentives to its users if they act as relays rather than investing on infrastructure.

4. Problems and Solutions

Diversity techniques are a good alternative to alleviate the effect of fading and the inexact knowledge of the channel state. Nevertheless, the integration of multiple antennas at the receiver to achieve spatial diversity is not an easy task because of the reduced size of mobile terminals. Moreover, provided a MIMO channel, spatial multiplexing provides an additional spatial dimension that poses a degree-of-freedom gain. These degrees of freedom lead to an increase in the capacity and depend on the characteristics of the MIMO channel. Finally, the scarcity of radio resources requires innovative mechanisms for its management, such as the use of network coding that allows encoding two different signals into a single stream. This section addresses all these problems and the adopted solutions.

4.1. MIMO integration in mobile devices: Virtual Antenna Array

The concept of Virtual Antenna Array (VAA) is illustrated in Figure 5. A BS with several antennas transmits encoded data streams as if it was a normal MIMO system towards a set of UEs, which form a VAA group. Each UE receives the complete data stream, extracts its own information and relays the information to the other UEs. Therefore,

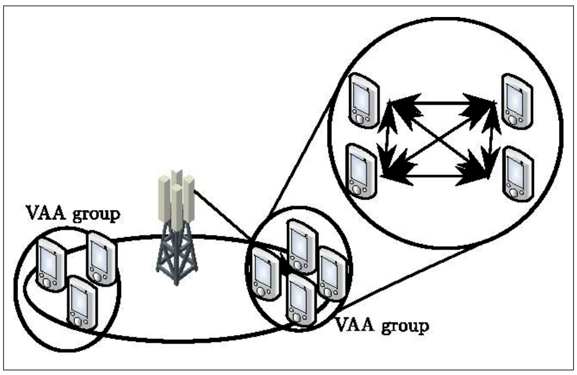


Figure 5. *Basic relay scheme.*

Nodes are not interested in cooperation without an incentive.

each UE receives information not only from the BS but also from the other UEs, increasing the diversity gain. Moreover, the correlation of the streams in the VAA is expected to be much lower than a conventional MIMO since UEs are sufficiently separated .

Dohler et al. were the first to analyze the capacity of a VAA [18]. The main conclusion is that the number of antenna elements available within a VAA should be greater than the number of antennas at the BS. However, the performance of a VAA is not as good as a conventional MIMO system due to the additional noise and latency introduced in the L1 relaying.

4.2. Facing the incomplete channel knowledge: transmit/receive diversity

Diversity consists in transmitting the same information over multiple channels that fade independently. Diversity techniques can be classified into time, frequency and space diversity:

- **Time diversity.** The same signal is transmitted several times in different time slots. Data will be affected differently at each slot and hence the probability of receiving the information free of errors increases.

- **Frequency diversity.** This technique is based on the fact that channel is frequency selective due to multi-path effect. Orthogonal Frequency Division Multiplexing (OFDM) systems exploit frequency diversity distributing the codeword among different subcarriers. Hence, it is possible to retrieve the information from subcarriers that have been erased by frequency selective fading.

- **Space Diversity.** This is achieved by means of multiple antennas at the transmit and/or receive side. The signals from different antenna paths are combined in the receive side to average the fading between antennas.

Of course, there are techniques that benefit simultaneously from more than one dimension of diversity. Space-time coding, proposed by Alamouti [19], is one of the most famous techniques. In this case, two consecutive symbols are combined and transmitted in two adjacent subcarriers using two transmit antennas.

An extension of the concept of space-time codes can be applied in mobile relaying to tackle the problem of how information is transmitted from the relays over time. These techniques are called Distributed Space-Time Block Codes (DSTBC). Unlike conventional space-time codes, DSTBC are subject to some challenging synchronization issues. First, the transmitters can be widely separated and can have different time references. Moreover, the delay of each RN-to-destination link can be different. This can cause a destructive combination of signals. There are some solutions that face the issue of synchronization between nodes participating in the cooperative communication, such as delay-tolerant distributed space-time codes [20] or space-time spreading [21].

George et al. studied the performance of Cooperative Distributed Space Time Block Codes (CDSTBC) [22]. The source transmits to the RN the first half of the Alamouti encoded sequence. The RN receives this signal and stores it in a buffer. In the second time slot, the source transmits to the destination the other half of the Alamouti encoded sequence while the relay sends its stored copy of the first transmission. From the point of view of the destination, a standard Alamouti encoded packet is received. Results show that this scheme outperforms direct link transmission schemes.

4.3. Demanding more throughput: MU-MIMO

Most of MIMO techniques have been traditionally used for point-to-point communications. These techniques can be extended to a multi-user scenario with some considerations. In UL, the BS has to use array processing and multi-user detection to separate the signals transmitted by different UEs. In DL, the receive antennas are distributed in the cell and UEs do not know the transmission scheme of other UEs. Therefore, the signals transmitted to a UE are interferences to the others. This interference can be removed or minimized through a proper processing at the transmitter called precoding. This precoding is selected with the help of Channel State Information (CSI).

Consider that the BS has M transmit antennas and K users have one antenna each. Let $x(k)$ be the symbols transmitted to the k-th user. The selected precoding matrix for the k-th UE is $W(k)$. It implies that the transmit symbol is a combination of the symbols belonging to other UEs. The received signal assuming flat fading channels is:

$$r(k) = \boldsymbol{H}(k)\boldsymbol{W}(k)x(k) + \boldsymbol{H}(k)\sum_{i=1, i\neq k}^{k} \boldsymbol{W}(i)x(i) + n(k)$$

$H(k)$ stands for the DL channel of the k-th user and $n(k)$ represents the Additive White Gaussian Noise (AWGN). The received symbol is composed of the desired symbol, the interference plus noise. The objective is to select a precoding matrix that minimizes the terms of interferences.

The selection of the most adequate technique depends upon the level of knowledge of the CSI. When the channel to all UEs is known at the transmitter side, Dirty Paper Coding (DPC) allows obtaining the same capacity as that of a channel without interference [23]. Another option is to use Block Diagonalization [24]. This method spatially decomposes the MIMO channel into mutually orthogonal sub-channels. The zero interference condition is achieved if the number of transmit antennas is greater than the sum of all the receive antennas considering all UEs. As alternative method, the selection of the precoding matrix can be based on the Signal-to-Leakage-Noise-Ratio (SLNR) [25, 26].

Regarding the feedback schemes, there exist several methods that can be used. Each UE can inform to the BS of the singular vectors corresponding to nonzero singular values. Then the BS would apply the above-described methods. Moreover, a UE could send the preferred precoding matrix through the Precoding Matrix Indicator (PMI). Another alternative is to transmit the spatial covariance matrix to each UE that can be used for SLNR methods. In UL, the precoding matrix is selected by the BS in an easier manner, since the BS can directly estimate the channel through the UL reference signals. In the same way, in a Time Division Duplexing system (TDD) with low to moderate speeds the reception is easier since duality between UL and DL can be assumed.

MU-MIMO is being recently applied in cooperative networks. In [27] Weng and Murch proposed a method that uses MU-MIMO to subtracts the interference in a two-way communication system.

4.4. Saving wireless resources: network coding

The first work on Network Coding (*NC*) was developed in [28] for a network known as butterfly network. Although the work in [28] is based on lossless wired communication, the concept of *NC* can be easily transferable to a wireless scenario thanks to the broadcast nature of wireless channels.

Figure 6 shows the general concept de *NC*. Consider a source *S* that wants to multicast the streams *X* and *Y* to two different destinations (*D1* and *D2*) through three intermediate nodes (*R1*, *R2* and *R3*). In a traditional network, the *R3* node is the bottleneck because it needs two frequency channels or time slots to deliver the information. For this reason, on the left side of Figure 6 it is showed that *R3* can only transmit *X* in a frequency channel (or time slot). However, if *NC* is applied, the *R3* node performs a combination of *X* and *Y*. As it is showed on the right part of Figure 6, the signal *X+Y* is transmitted by *R3* in the same frequency channel (or slot).This operation is

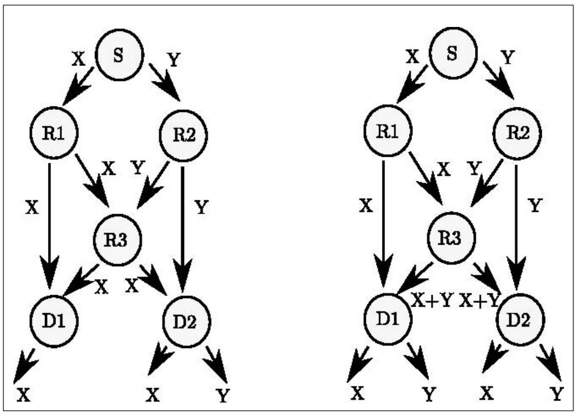


Figure 6. *NC applied to the butterfly network.*

Research trends are now addressing a new paradigm of wireless network in which UEs become mobile relays.

often carried out using an algebraic structure called Galois Field (*GF*). The set of *GF*(2) is {0,1} and its elements obey the eXclusive *OR* (*XOR*). In this way, R3 node transmits the *XOR* of *X* and *Y* in a channel or in a slot, and the destination nodes can obtain *X* and *Y*.

There are several studies addressing *NC* applied to cooperative networks. *NC* allows achieving spatial diversity in a distributed manner. The scenario considered is composed of *N* UEs (sources), one destination and *M* candidate RNs, although only one is selected to forward the signal from the source. Two phases are defined: a Direct Transmission Phase (DTP) and a Dynamic-Network-Coding-and-Forwarding Phase (DNCFP). In conventional cooperative algorithms, N time slots are required to send data from the source to the destination. Time Division Multiplexing Access (TDMA) strategy is used in DTP to distinguish data flows from different sources. Note that, instead of sending data towards the destination directly, the *RN* overhears the signal sent from the source. For this reason, *N* time slots are also required to send the N signals from the *RN* to the destination in the second phase. However, according to [29], the number of required time slots in the second phase is reduced to 1 thanks to *NC* operation. In this case, the *RN* transmits in the second phase a combination of the *N* transmitted signals of the first phase. In the paper, the diversity-multiplexing trade-off is analyzed. The obtained diversity with this method is the same as conventional cooperative algorithms since in both cases the destination obtains the desired signal from two paths, one from the source and the other from the relay. However, the multiplexing gain can be improved by increasing *N*.

In [30], a MIMO system comprising *N* transmit antennas and N receive antennas, both in the *RN* and in the destination, is incorporated into the study. In the DNCFP phase, the *RN* randomly selects one antenna to send the composite data flows from the different sources. The cooperative protocol utilized is Decode and Forward (DF). With the objective to compare this system with conventional schemes, Orthogonal Space-Time Coded (OSTC) DF and TDMA DF are introduced. The theoretical analysis reveals that all schemes present the same order of diversity, *2N*. However, the resource consumption is reduced when TDMA is used.

As discussed, if *NC* is used a total of *N+1* time slots are required to carry the information from the source to the destination. In order to reduce the transmission time, a new technique called Physical-Layer Network Coding (PLNC) has been recently proposed in the literature [31]. In conventional networks, interference is seen as a harmful effect in any mobile communication system. However, the implicit concept of PLNC is to add signals from different sources at the Electro-Magnetic (EM) level instead of at bit level so that signals can be simultaneously transmitted. The summation of EM signals can be mapped to GF additions of digital bit stream. However, several troubles are found when addressing this type of techniques. Synchronization both at symbol and carrier level is required to avoid performance penalties. However, some recent papers as [32] propose that certain asynchrony at symbol level can be advantageous since it makes the system be more robust against phase offsets of the carrier.

5. Discussion and Future Trends

This paper has presented an overview on mobile relaying technologies that are being addressed by the international research community for next generation wireless systems. Concerning technological status, 3GPP has recently standardized fixed relaying in Release 10 and there are only some preliminary studies on MR over trains conducted within the Release 11 ongoing activities.

Research trends are now addressing a new paradigm of wireless network in which UEs become MRs and assume an active role in the network to guarantee the ubiquity of high quality services. However this is a challenging scenario with a number of open questions that need to be solved. Some of the current answers were discussed in Section 3. Network coding has timidly been discussed in the 3GPP [33, 34]. It can be interesting in certain scenarios such as DL/UL unicast with relays or multicast retransmission. On the other hand, a key topic is why users are willing to cooperate. Providers must figure out how to encourage users to cooperate. A possible trend is that users cooperate within a Close Subscriber Group (CSG), for instance, your family or your colleagues. MR can also improve spectrum efficiency by exploiting more advanced antenna arrays and signal processing algorithms. Both MU-MIMO and space/time/frequency codes have been proposed in Release 10. An extension of these techniques is under discussion and will be included in following releases. Following the general philosophy of the 3GPP to reduce the complexity of the system, techniques as VAA can be an excellent solution to avoid implementing high order MIMO in mobile devices.

Among others, important research areas for the future of mobile relaying are:

- The design of flexible and dynamic protocols and forwarding strategies that allow for the integration of cooperation in conventional relaying.
- The design of algorithms robust against imperfection on CSI at the transmitters and relays.
- The trade-off between macro-diversity gains and the addition signaling overhead required by cooperative relaying.
- Proper selection of relay, relay channel and relay power.
- The definition of incentives that does not require for additional signaling in the network.

Acknowledgements

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