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A Coded Cooperative Networking MAC protocol in non transparent multihop WiMAX network

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Abstract

IEEE 802.16j mobile multi-hop relay (MMR) was proposed to gain coverage extension and throughput enhancement. The objective of this work, is to suggest a coded cooperative networking MAC protocol in non transparent multihop WiMax network. The proposed design takes in consideration network coding approach between relays. We try to address the division of an IEEE 802.16j frame into different zones. We suggest a frame structure that supports 3 hops non transparent TTR mode. Related work and the 802.16j capability are also deeply discussed.

Keywords: *Cooperative, network coding, frame, multihop, IEEE 802.16j, MAC.*

1. Introduction

Cooperative communication (CooCom) [1, 2 ,3 ,4 ,5, 53] is a recent paradigm for wireless relay networks [6, 7, 8, 9, 10], proposed as a way to improve wireless network reliability and capacity. The main technical benefits coming along with cooperative communications are higher coverage, improved spectrum usage, lower energy consumption, increased location estimation accuracy, etc.). The broadcast nature of the wireless medium is the main enabler of cooperative communications.

Coocom enables single-antenna nodes in a multi-user environment to share their resources to jointly transmit information in order to achieve an improvement in overall performance and reap some of the benefits of multiple-input, multiple-output (MIMO) [11, 50, 51] systems. The classical relay channel model [6,12,13,14, 21, 52] is comprised of three terminals a source that transmits information, a destination that receives information, and a relay that both receives and transmits information in order to enhance communication between the source and destination. Cooperation is a generalization of the relay channel to multiple sources with information to transmit that also serve as relays for each other. Combinations of relaying and cooperation are known as cooperative communications.

This is realized via the application of cooperative diversity techniques that take advantage of the spatial diversity offered by cooperation between wireless terminals. Diversity increases capacity and provides robustness against fading. The most common diversity methods are spatial diversity using multiple antennas, temporal diversity using automatic repeat request schemes or block interleaving with error correction, and frequency diversity using frequency spreading, frequency hopping, or orthogonal frequency division multiplexing techniques. Cooperative diversity refers to the class of techniques where diversity benefits are gained via the sharing of information between multiple cooperating terminals in a wireless network. Several relaying cooperative strategies [15] for wireless relay networks are proposed:

- decode- and-forward [17, 18],
- amplify-and-forward [19, 47],
- compress–and-forward [20],
- selection relaying scheme [16, 22→ 25].
- opportunistic relaying scheme[16, 26],
- coded cooperation (CC) [27, 28],
- Space-time CC [29, 30]

In decode and forward method a cooperating node first decodes signals received from a source and then relays or retransmits them. The receiver at the destination uses information retransmitted from multiple relays and the source (when available) to make decisions. Perfect regeneration at the relays may require retransmission of symbols or use of forward error correction (FEC) depending on the quality of the channel between the source and the relays. This may not be suitable for a delay limited networks. In amplify and forward each cooperating node receives the signals transmitted by the source node but don't decode them. These signals in their noisy form are amplified to compensate for the attenuation suffered between the source-to-relay links and retransmitted. The destination requires knowledge of the channel state between source-to-relay links to correctly decode the symbols sent from the source.

In compress and forward the received signal is only quantized instead of being fully decoded, the quantized symbols are not directly repeated in phase 2 they are compressed by Wyner-Ziv coding [31]. The selection relaying schemes choose the strategy with best performance based upon channel measurements between the cooperating terminals. In an opportunistic relaying scheme (ORS) only the best relay is allowed to cooperate with the source. If channel conditions are not statistically equal for all relays, ORS may be unfair among relays. That is, relays with the worst channel conditions are never selected and all the cooperation is performed by a reduced set of relays. This can induce a negative effect in the network behavior as one (or more) relays can waste all the battery energy for the sake of cooperation.

The coded cooperation provides cooperation diversity by distributed Forward Error Correction (FEC) coding and considers the result of the error check for its relaying decision. If a user is not able to correctly decode the partner's bits it forwards its own data during the second phase. The Space-time CC exploit spatial diversity available among a collection of distributed terminals that relay messages for one another in such a manner that the destination terminal can average the fading, even though it is unknown a priori which terminals will be involved. In particular, a source initiates transmission to its destination, and many relays potentially receive the transmission. Those terminals that can fully decode the transmission utilize a space-time code to cooperatively relay to the destination.

Many other strategies have been proposed. In [32] new cooperative strategy for ad hoc networks that are more spectrally efficient than classical Decode & Forward (DF) protocols was proposed. Using analog network coding was suggested in order to improve spectral efficiency of the cooperative system by relaxing the orthogonally constraint, though preserving the practical half-duplex constraint.

Although all these schemes employ different techniques to process the relayed data, all of them employ at least two phases per cooperation cycle separated for the reason that wireless terminals cannot transmit and receive simultaneously at the same time and frequency. While in the first phase the users exchange their data, in the second phase the users help each other by relaying the data/signal. The emerging IEEE 802.16j standard may allow w/o relay transmissions in the second phase.

The cooperative connectivity of a wireless relay network is defined as the set of communication links between pairs of terminals that are used in the transmission of an information signal from a source terminal to a destination terminal. Relay terminals are defined to cooperate with the source terminal when they transmit a signal that helps the destination terminal to successfully decode the original information signal. The ways that cooperating terminals can be connected to each other in wireless relay networks, the constraints imposed by the availability of different system resources and the achievable combinations of communication links between cooperating terminals are also deeply presented in the literature [54].

Recently, network coding [33, 34, 35,] as well has received a lot of attention for its potential advantages in improving throughput and enhancing robustness for multi-source systems. The basic principle of network coding is to linearly combine multiple independent information flows into one flow to transmit. There have been several proposals for applying network coding to multi-source relaying networks, with or without cooperation. The interaction between Cooperation and Network Coding [36] has recently received a significant deal of attention, as a combination of the two brings novelty, flexibility and improved performance. However, there is a lack of studies about real-world scenarios.

Multihop relaying is already part of the standards currently being developed for wireless broadband systems [37] such as 802.16j [38] and 802.16m [39], which is an indication of growing consensus on the effectiveness of cooperative communication. However, at this stage, there are many open issues regarding good 802.16j relay network solutions:

- While there have been a few initial studies on IEEE 802.16j MMR networks, not much is really known about the performance of such systems. This makes it very difficult to have clear ideas of the potential of this technology.
- The current standard does not specify how the radio resource allocation will be done.
- Some initial studies on the design of 802.16j system have been carried out. The issues relative to the planning of multiple relays is still open.

No previous work has specifically look to the implementations issues of a coded cooperative networking MAC protocol over 802.16j systems. More specifically, the focus of this contribution is to propose a coded cooperative networking MAC protocol in fixed broadband wireless access systems with multihop relay Wimax networks, which we denoted it $CCNMAC_{MHRwimax}$ "**C**oded **C**ooperative **N**etworking **MAC** protocol for **M**ultihop **R**elay Wimax networks". Such proposal require firstly a deep research on coding schemes [40, 41] used for combining, on relaying techniques used for mutually exchanging data, on multiple access methods to limit interference and overhead, on cooperation aware resource allocation such as selecting partners[42, 43] and cooperation level [44, 45] , on routing methods [46] in multi-hop cooperative networks. Secondly we must focus on the practical issues for cooperative networking when trying to apply cooperation in an existing standard, such as IEEE 802.16j networks.

Researches on cooperative mechanisms at MAC layer are commonly related to WLAN networks [55, 56, 57, 58] and only some works for WMAN networks [59,60].

In [61] the authors propose A user scheduling and radio resource allocation algorithm for two-hop wireless relay networks in order to efficiently integrate various cooperative diversity schemes for the emerging IEEE 802.16j based systems. The analysis of the system with this scheduler shows that a simple cooperative diversity scheme which dynamically selects the best scheme between conventional relaying and direct transmission is promising in terms of throughput and implementation complexity.

The paper is organized as follows. In this section we have briefly reviewed related work. A reasonably detailed description of the 802.16j capability based on the current draft is presented in section 2. In Section 3, Frame structure for MMR in non transparent mode with tunneling and network coding approach is proposed. Finally, the paper is concluded in section 4.

2. IEEE 802.16j capabilities

The IEEE 802.16j is an amendment to the IEEE 802.16e standard to enable the functionalities of interoperable RSs and BSs. The IEEE 802.16j standard is currently being developed for increasing the coverage area of the IEEE 802.16e standard via the deployment of fixed or nomadic relay terminals.

In this section, the key system features and the capabilities of the IEEE 802.16j MR network are overviewed. The discussion will focus on two particular aspects the different relay modes that are defined and the frame structure that is proposed.

2.1 Relay mode

The basic system architecture considered by IEEE 802.16j is shown in Fig.1, where two kinds of radio links are identified: access link and relay link. BS that is capable of supporting multi-hop relay is called MR-BS. The access link is the radio link that originates or terminates at an MS, which is either a downlink (DL) or an uplink (UL), defined in IEEE 802.16-2004. The relay link is the radio link between an MR-BS and an RS or between a pair of RSs, which can be either uplink or downlink [68]. Based on the functionality of an RS, IEEE 802.16j has classified the RS functionality into two modes: transparent and non-transparent.

- In the transparent mode[62, 63], the RSs do not forward framing information, and hence do not increase the coverage area of the wireless access system; consequently, the main use case for transparent mode relays is to facilitate capacity increases within the BS coverage area. This type of relay is of lower complexity, and only operates in a centralized scheduling mode and for topology up to two hops.
- In Non-transparent mode: The RSs generate their own framing information or forward those provided by the BS depending on the scheduling approach (i.e., distributed or centralized). They can support larger coverage areas and hence are mainly used to provide increased coverage. Fig.2 illustrates the two modes.

Table 1 below gives a comparison between the transparent and non-transparent relay modes [63, 64, 65].

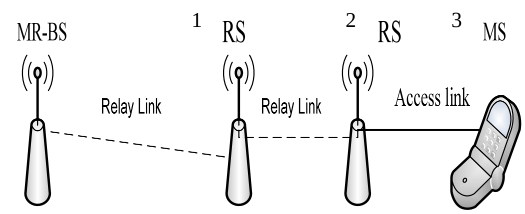
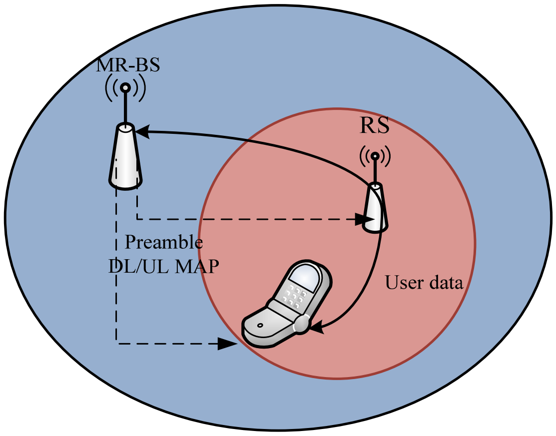
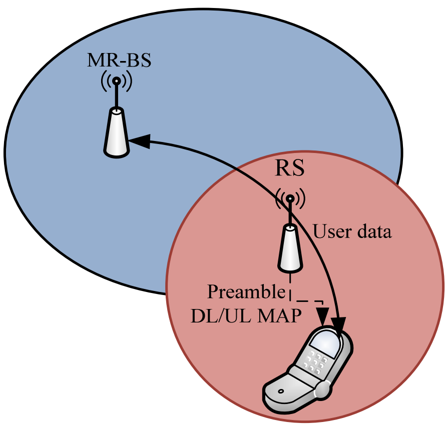


Fig.1 IEEE 802.16j basic system architecture



Transparent Mode



Non-transparent Mode

Fig.2 Transparent and Non-transparent relay modes architecture

Table 1: Transparent and Non-transparent relay modes

	Transparent RS	***Non-Transparent RS***
Coverage extension	No	Yes
Number of hops	2	> 2
Inter RS cell interference	NA	High
HO between RSs	None	Yes
Performance	In BS coverage: High Outer BS coverage: -	In BS coverage: same as16e Outer BS coverage: medium
RS Cost	Low	High
Scheduling	Centralized only	Centralized/ distributed

There are two types of non-transparent relays available in 802.16j: Time-division Transmit and Receive (TTR) relay and Simultaneously Transmit and Receive (STR) relay. The TTR relay act in the access zone as BS and in relay zone it acts as relay.
For this work, we have considered the non-transparent mode with two TTR relays nodes.

2.2 Frame structure for MMR

As the frame structure defined in the earlier IEEE 802.16e standards was designed for single-hop wireless networks, modifications were required to support relay network architectures. The IEEE 802.16e have adopted orthogonal frequency-division multiple access (OFDMA) as the primary channel access mechanism for non-line-of-sight (NLOS) communications in the frequency bands below 11 GHz. The basic unit of resource for allocation in OFDMA is a slot, which comprises a number of symbols in time domain, and one subchannel in frequency domain. The base station divides the timeline into contiguous frames, each of which further consists of a downlink (DL) and an uplink (UL) subframe. For the case where MR-BS supports more than two-hop relay, the DL and UL sub-frames shall include at least one access zone and may include one or more relay zone to enable RS operating in either transmit or receive mode. The DL/UL access zones are dedicated for transmission between MSs and their access stations (MR-BS or RS), and they are fully compatible with the 802.16e frame structure. The DL/UL relay zones are dedicated for transmission between MR-BS and the RS or between two RS. In each relay zone, BS and RS can stay in the mode of transmission, reception or being idle. However, it is not expected to have BS or RS switch from one mode to the other within the same zone. In order to give wireless device sufficient time to switch from one mode to another, the corresponding time gap (e.g., TTG and RTG) is inserted between two consecutive sub-frames. The IEEE Std. 802.16j specifies the following gaps:

- R-TTG: RS transmit/receive transition gap between uplink access zone and uplink relay zone in RS frame between DL access zone and DL relay zone in RS frame
- R-RTG: RS receive/transmit transition gap between uplink access zone and uplink relay zone in RS frame.

The case where each DL and UL sub-frame comprises of more than one relay zones is shown in Fig. 3.

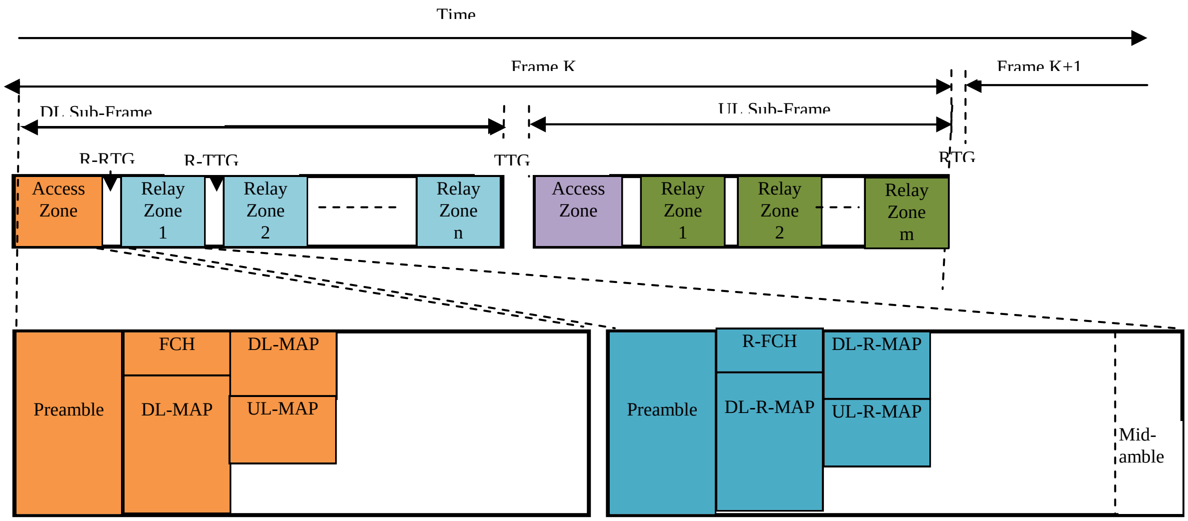


Fig.3 Frame Structure for MMR

The frame structure design is more challenging in the new mobile multihop relay based (MMR) network architecture, as numerous dimensions of design constraints and challenges have been introduced. In the literature frame structure design has received some attention In [48][49] a generic frame structure to support mobile multihop relay (MMR) operation of IEEE 802.16j, while maintaining the backward compatibility with the legacy 802.16e mobile stations was proposed and analyzed.

The packet construction mechanism in IEEE 802.16/16e standard, which was designed for handling traffic solely on a per-connection basis, cannot apply on the relay link directly, as it may render a potential bottleneck and preponderantly limit the overall network capacity. As a solution, in [58] the authors propose two schemes at the MAC layer, namely MPDU concatenation and MSDU aggregation.

3 Frame structure for MMR in non transparent mode with tunneling and network coding approach

This section provides design frame structure for multi relay hops (MR-BS, RS1, RS2) in non transparent mode. The proposed design takes in consideration network coding approach between relays. An envisioned topology is illustrated in figure 1, wherein RSs help MR-BS communicate with those MSs that are either too far away from the MR-BS. In other hand RSs can also have their own traffic to MSs. In this case, both the MR-BS and the relay transmit control data at the beginning of the frame. This way, the MS can synchronize with the relay, which is synchronized with the MR-BS.

The main drawback in the non-transparent case is that now the relay and BS are transmitting simultaneously in time and possibly, frequency. The immediate drawback is an increase in interference, particularly in the preamble and control channels. Clearly, power control and frequency reuse, which largely are left up to manufacturers, are crucial to non-transparent relaying. Further, non-transparent relays likely are more sophisticated (and thus, more expensive) than transparent.

Therefore, our challenge is to design a transmission mechanism suitable for wireless multi-hop networks, which linearly combine information flows from (BS, RS1, RS2) into one flow to transmit.

The IEEE 802.16j is also devoted to defining a new MAC message family (called R-MAC) between the MRBS and the subordinate RSs. A fundamental part of the R-MAC is what can be regarded as a tunnel connection, which is identified by a special tunnel CID (T-CID). In what way to use these tunnels is not specified in 802.16j D2 [59]. In this work we take in consideration Hop by Hop Tunnel Establishing (HHTE). In HHTE, RS_i receives the MPDU from MS, MR-BS or RS_j decodes it, and determines that it needs to be processed by each hop. RS_i encapsulates the MPDUs and sends it. Although the tunneling is optional, tunneling simplify the relaying process in multi-hop environment.

In order to explain our approach, we consider the topology illustrated by figure 1 which corresponds to 3 hops non transparent mode. We try to address the division of an IEEE 802.16j frame into different zones. We suggest the frame structure shown in fig.4 to support 3 hops non transparent TTR mode. We consider that MR-BS has the data flow X_0 to transmit to MS3 and each relay node RS_i has a data flow denoted X_i to be transmitted to the MS3. Moreover, the MS3 terminal has the data flows Y_0 and Y_i to send respectively to MR-BS and $RS_{i.}$ The different interval time are denoted (T1, T2, T3,T4, T5, T6).

In table 2 we illustrate the data flows assigned and exchanged between the different hops.

Table 2: Data flow for support 3 hops non transparent mode

T1	T2	T3	T4	T5	T6
RS2 → MS3	MR-BS → RS1	RS1 → RS2 RS1 →MR-BS	MS3 → RS2	RS2 → RS1	RS1 → RS2 RS1 →MR-BS
X2k, X1(k-1) , X0(k-1)	X0k	(X0k xor Y0(k-1)), (X1k)	Y2k, Y1(k) , Y0(k)	Y0(k) , Y1(k)	(Y0k xor X0k), (X1k)

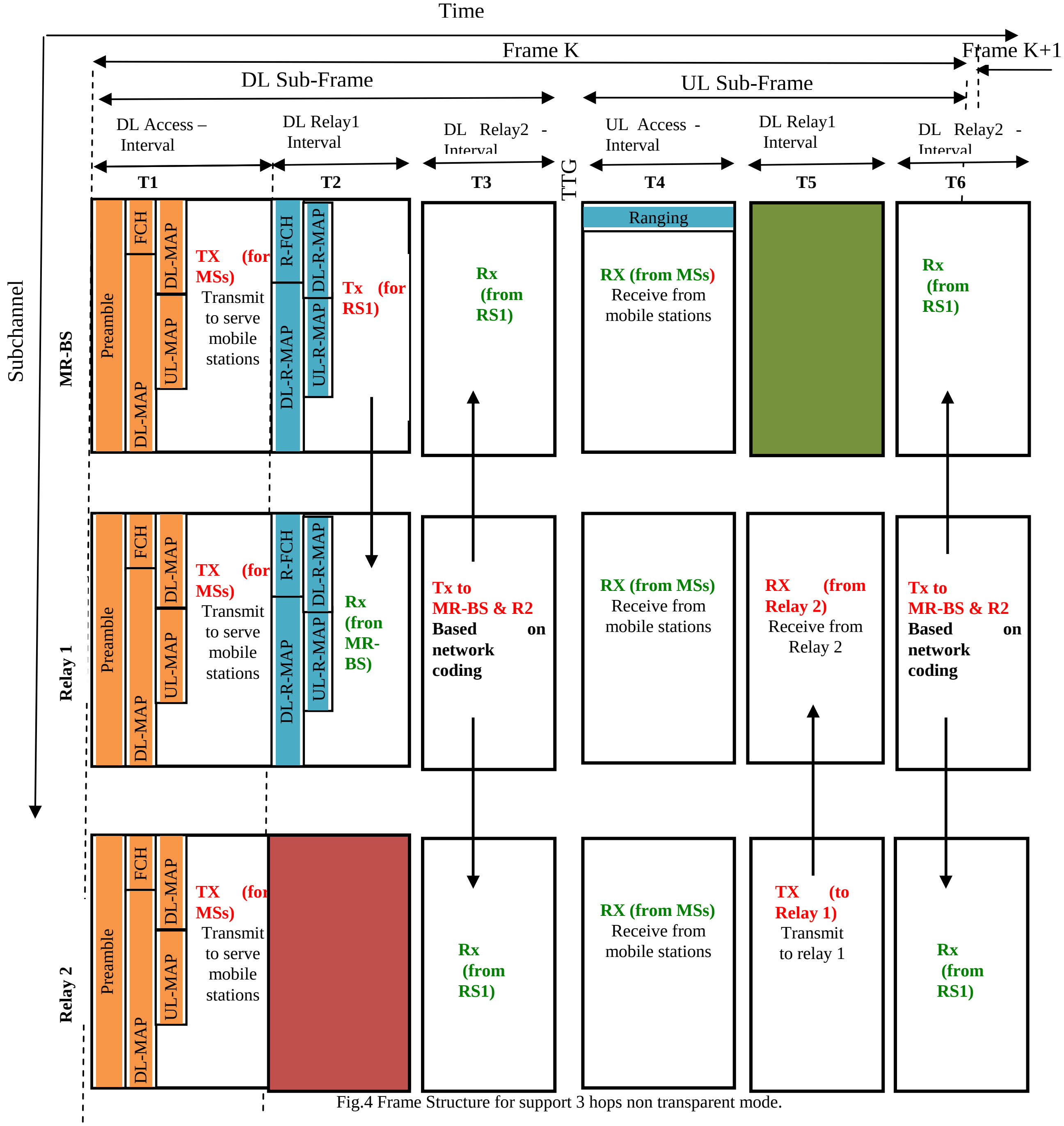


Fig.4 Frame Structure for support 3 hops non transparent mode.

In order to enhance the reliability of the wireless link, retransmission protocols have been widely adopted in wireless systems. Usually, they assume that lost packets within a cell have to be retransmitted from the corresponding BS based on the ARQ protocol. In this case, The MR-BS receives twice the data flow $Y0_k$ (in $frame_k$ and $frame_{(K+1)}$) and the RS2 receives twice the data flow $X0_k$ (in T3 and T6) this is can avoid the repeated retransmissions performed by the BS that reduce latencies to receive packets correctly.

4 Conclusions

In this paper, we have presented a coded cooperative networking MAC protocol in non transparent multihop WiMax. The proposed solution takes in consideration network coding approach between relays. The suggested frame structure supports 3 hops non transparent TTR mode.

In IEEE 802.16 based multi-hop networks many issues are still open both in PHY and MAC layer and specially those taken in consideration cross layer interaction. Key issues such as multi-hop frame structure, scheduling mechanism, support for QoS and many other requirements are under consideration. In future work, we will consider more extensive simulation to compare our scheme with other schemes.

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