A Cooperative Mac For Energy Efficient Relying

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ABSTRACT
LTE-A based system used fixed relays which are not suitable for wireless network. In wireless network terminal relays is most beneficial scheme but it is typically battery operated with limited processing and transmission capabilities. To reduce energy consumption an energy efficient cooperative medium access control protocol has been used which maximize the networks lifetime. In this scheme the best relay candidate broadcast a beacon message in order to inform all other candidate relays about its cooperative transmission for preventing collision and saving energy consumption of wireless network.

1. INTRODUCTION
The technological foundation of fourth generation (4G) cellular systems was outlined in the Long Term Evolution Advanced (LTE-A) standards which enable communication rates of 100 Megabits per second for mobile communications and 1 Gigabit per second for nomadic ones. In LTE-A the deployment of wireless intermediate communication-assisting nodes, known as relays, was standardized for the first time. Under ideal conditions it has been envisioned that the deployment of relays will enhance the network coverage and will enable reliable communication at the cell periphery. Despite the envisioned gains of LTE-A based systems, practical field tests indicate that slight deviations from the ideal conditions can result in significant loss in achievable rates and service coverage. We identify relaying as one of the most effective and enabling components of the LTE-A standard.

However, this standard suffers from a major weakness that results from the assumptions that the relaying nodes are static, their locations are known and their number is fixed. While these assumptions facilitate the design of the cellular system, they limit the scope of relay usability. As an alternative, we consider a cellular system in which the wireless terminals (WTs), in addition to transmitting their own signals, act as relays to assist other WTs. In such a system the number of relays scales with the number of WTs offering the system designer significantly more degrees of freedom. However, using WTs as relays presents a number of challenges, including: the mobility of the relaying WTs, the incidental manner in which the relays access the network, the resource blocks (RBs) to which each relay is entitled, the relaying mechanism used by each relay, and the way in which the power is allocated across frequency bands. The energy consumption of wireless networking may be beneficially reduced by exploiting a range of cooperative communications techniques, which have recently attracted substantial research attention. However, the original higher layer protocols such as for example those of the 802.11 system have not been designed for cooperative communications and hence they may erode the benefits of cooperative communications all together. Hence, it is very important to appropriately design the higher layer protocols, especially the Medium Access Control (MAC) protocol for cooperative systems.

The contributions found in the literature on designing cooperative MAC protocols may be classified into two categories according to the number of relay nodes involved in cooperation, namely into multiple relay aided and single relay assisted scenarios. Multiple relay selection is capable of offering considerable throughput improvements and outage probability reduction, albeit at the cost of eroding the energy efficiency unless sophisticated cross layer- operation aided physical layer processing, such as advanced beamforming, is employed .the other hand, single relay selection aided cooperation is capable of providing beneficial energy savings although they tend to complicate the protocol design. More explicitly, proposed a single relay selection aided MAC protocol, where each low data rate node has to maintain a cooperative parameter table in order to record all the required information of the potential candidate relays. As a result, a large amount of extra control messages are required in order to collect the associated information.

2. OVERVIEW
LTE-A: Long Term Evolution Advanced

The fourth generation (4G) of wireless cellular systems has been a topic of interest for quite a long time, probably since the formal definition of third generation (3G) systems was officially completed by the International Telecommunications Union Radio communication Sector (ITU-R) in 1997. A set of requirements was specified by the ITU-R regarding minimum peak user data rates in different environments through what is known as the International Mobile Telecommunications 2000 project (IMT-2000).

The requirements included 2048 kbps for an indoor office, 384 kbps for outdoor to indoor pedestrian environments, 144 kbps for vehicular connections, and 9.6 kbps for satellite connections. With the target of creating a collaboration entity among different telecommunications associations, the 3rd Generation Partnership Project (3GPP) was established in 1998. It started working on the radio, core network, and service architecture of a globally applicable 3G technology specification. Even though 3G data rates were already real in theory, initial systems like Universal Mobile Telecommunications System (UMTS) did not immediately meet the IMT- 2000 requirements in their practical deployments.

Hence, the standards needed to be improved to meet or even exceed them. The combination of High Speed Downlink Packet Access (HSDPA) and the subsequent addition of an Enhanced Dedicated Channel, also known as High Speed Uplink Packet Access (HSUPA), led to the development of the technology referred to as High Speed Packet Access (HSPA) or, more informally, 3.5G. Motivated by the increasing demand for mobile broadband services with higher data rates and Quality of Service (QoS), 3GPP started working on two parallel projects, Long Term Evolution (LTE) and System Architecture Evolution (SAE), which are intended to define both the radio access network (RAN) and the network core of the system, and are included in 3GPP Release 8. LTE/SAE, also known as the Evolved Packet System (EPS), represents a radical step forward for the wireless industry that aims to provide a highly efficient, low-latency, packet-optimized, and more secure service.

However, by the time the standard development started, the ITU-R framework for 4G systems was not in place, and later research and measurements confirmed that the system did not fully comply with ITU 4G requirements. For this reason, the term 3.9G has been widely used with the expectation of their evolving towards official 4G status in due course. Before 3GPP started working in the real 4G wireless technology, minor changes were introduced in LTE through Release 9. In particular, femtocells and dual-layer beam forming, predecessors of future LTE-Advanced technologies, have been added to the standard. The formal definition of the fourth generation wireless, known as the International Mobile Telecommunications Advanced (IMTAdvanced) project, was finally published by ITU-R through a Circular Letter in July 2008 with a call for candidate radio interface technologies (RITs). In October 2009, six technologies were submitted seeking for approval as international 4G communications standard. 3GPP's candidate is LTE-Advanced, the backward-compatible enhancement of LTE Release 8 that will be fully specified in 3GPP Release 10. By backward compatibility, it is meant that it should be possible to deploy LTE-Advanced in a spectrum already occupied by LTE with no impact on the existing LTE terminals. Other candidate technologies are IEEE 802.16m and China's Ministry of Industry and Information Technology TD-LTE-Advanced (LTE-Advanced TDD specification).

In this paper, we design an energy-efficient cooperative Medium Access Control (MAC) protocol combined with physical layer power / rate control in order to minimize the energy consumption. Based on the Channel State Information (CSI) and relay-to-destination distance, the potential candidate relays carry out autonomous decisions for minimizing the transmission power required for forwarding their data, when relying on their cooperation. Simulation results demonstrate that our scheme is capable of providing considerable energy savings, while maintaining the target Frame Error Ratio (FER), which is achieved at the cost of Introducing a modest additional MAC overhead.

This paper proposes an autonomous MAC layer protocol relying on single relay selection and incorporates a physical layer power / rate control technique for the sake of minimizing the network's energy consumption, where the main distinguishing aspects of our protocol are:

1) We specifically design the cooperative MAC layer protocol by considering the hidden node problem and the resultant collision issues.

2) We exchange the order of data and control messages so that correct reception can be guaranteed at the relays.

3) We design a cooperative retransmission regime activated at the source for recovering the unsuccessful cooperative transmissions, which may also be invoked for direct non cooperative transmissions.

3. BACKGROUND

The steep rise in the number of WT users worldwide has been increasing over the past decade. This is essentially due to the involvement of electronic and mobile commercial activities, multimedia streaming and security applications, which place pressing demands on the data rates and coverage requirements of wireless networks. In order to meet the rising demands, the LTE-A standards, laid out for 4G cellular networks, have considered the deployment of fixed relays to assist the communication between source and destination nodes.

Despite the envisioned advantages of relay deployment, field tests of LTE-A based systems indicated that the actual rates and coverage capabilities of these systems are well below the prospective ones. It is suspected that the main cause of these deficiencies is the limited number of fixed relays that can be deployed in practice and the difficulty of optimizing their locations. To mitigate the difficulties encountered by systems based on LTE-A standards, communication resources must be procured at a rate that scales with the rising demands.

One approach to do that is to enable the WTs to act as relays, thereby providing a means for increasing the data rates and improving the coverage of future wireless networks. In contrast with the fixed relays proposed in LTE-A, terminal relays are typically battery operated with limited processing and transmission capabilities.

The location of relaying terminals cannot be controlled; they may be non uniformly distributed and may access the network in an incidental fashion. Furthermore, relaying WTs may operate under different premises regarding the number of available transmit and receive antennas and available CSI. Hence, the goal is to address the different aspects of terminal relaying, to provide practical solutions and useful insights into its potentials and limitations.

POROTOCOL DESCRIPTION

A. *Configurations and Assumptions*

Before introducing the cooperative MAC protocol advocated, the following assumptions are made:

1) Consider a cooperative network topology, which consists of a single source S as well as destination D and a total of N relays R = {R1, . . . ,RN}, as seen in Fig 1. We define a transmission burst as a single transmission attempt, excluding any subsequent retransmission attempts. All the channels involved are assumed to undergo quasi-static fading, hence the complex-valued fading envelope remains constant during a transmission burst, while it is faded independently between the consecutive transmission bursts.

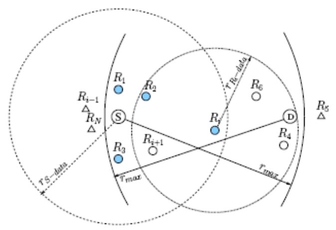

Fig. 1. The cooperative topology consists of one source $\mathcal{S}$, one destination $\mathcal{D}$ and a total of N relays $\mathcal{R} = \{\mathcal{R}_1, \ldots, \mathcal{R}_N\}$.

2) Within a given transmission burst, the duplex bidirectional channels between a pair of actively communicating nodes are assumed to be identical, while the channels of any of the remaining links are independent. We assume perfect channel estimation for all nodes for their own channels, but no knowledge of the remaining links is assumed.

3) We define the transmission duration as T and the transmission rate as $R = 1/T$. For simplicity, we assume a direct reciprocal relationship between T and R. Hence, the maximum transmission energy becomes Emax = Pmax/Rmin, where we assume that all nodes are limited by the same maximum transmission power Pmax and only the transmissions involving the source have the flexibility of employing different transmission rates corresponding to adaptive-rate channel coding and adaptive modulation modes, such as QPSK, 16-QAM and 64-QAM. Based on the Request-To-Send (RTS) / Clear To-Send (CTS) signaling of the IEEE 802.11 protocol, we develop an autonomous cooperative MAC protocol that selects the best relay from a set of N potential relays, as illustrated in Fig 1. The proposed signaling procedure is detailed in Fig 2, which includes three phases, as detailed below.

B. *Phase I: Initialization*

Before the source node transmits any data frame, it issues a RTS message at the Maximum transmission power Pmax and the minimum transmission rate Rmin for reserving the shared channel similar to the legacy IEEE 802.11 protocol, as shown in Fig 2. When the destination receives the RTS message correctly, it replies with a CTS message, again, employing the maximum transmission power Pmax and the minimum transmission rate Rmin, as shown in Fig 2

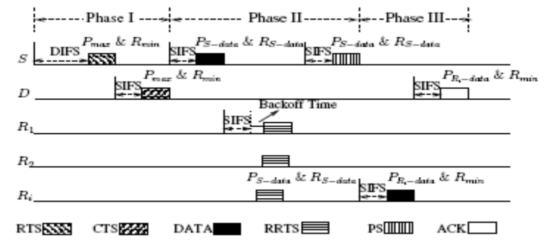

Fig. 2. The overall signalling procedure. RTS: Request-To-Send; CTS: Clear-To-Send; RRTS: Relay-Request-To-Send; PS: Please-Send; ACK: Acknowledgment; DIFS: Distributed Interframe Space; SIFS: Short Interframe Space.

To elaborate a little further, we include the transmitter's position information into the RTS and CTS signaling frame, thus any relay nodes in set R which can overhear both the RTS and CTS messages will be aware of the imminently forthcoming transmission, as well as of the position information of the source and destination. Hence, these relay nodes - which are denoted by filled or hollow circles in Fig 1 - form a potential cooperative relay set $Rc \subset R$, where the information of the source-to-relay distance dSRi , $\forall i \in Rc$, the relay-to-destination distance dRiD, $\forall i \in Rc$ and the source-to-destination distance dSD become available to each of the relay nodes belonging to the set Rc.

C. *Phase II: Relay Selection*

After the initialization phase, the relay selection procedure is constituted by a data transmission and two beacon message exchanges, as detailed below.

Step I: Call for Cooperation:

As seen in Fig 2, after receiving the CTS message from the destination, the source node waits for a Short Interframe Space (SIFS) interval, before broadcasting the data frame at a *reduced* transmission power of Ps-data or an *increased* transmission rate of RS-data. It is important to note that the specifically selected transmission power of Ps-data or the transmission rate of RS-data is included in the data frame so as to allow the relay node to reply to the source with a beacon message employing the same transmission power or rate 1.

Remarks: Both our power-and-rate adjustment strategies aim for reducing the transmission energy consumption. Transmission at an increased rate necessitates an increased SINR at the receiver for achieving an acceptable physical layer FER. Hence, when the transmission power remains constant, increasing the transmission rate typically leads to a reduced transmission range, since usually an increased SINR is required. This, in principle, may be deemed equivalent to the reduced-power transmission strategy. However, maintaining a constant transmission power while varying the transmission rate is always more desirable from a network stability perspective, rather than ramping up the power in the interest of maintaining the target FER.

Step II: Relay Ready to Cooperate:

If a relay node $Ri \in Rc$ received the data frame correctly, it calculates the minimum transmission power PRi−data that is required for successfully forwarding the data frame to the destination by employing the minimum possible transmission rate of Rmin. This may be achieved by assuming the knowledge of the channel between relay Ri and the destination D. This channel may be deemed to be identical to the channel estimated during the reception phase of *Ri*, provided that the Ri-D and D-Ri links use the same carrier-frequency in a Time-Division-Duplex (TDD) fashion.

Given the contending set *Rcc*, the specific relay that has the shortest relay-to-destination distance drd is granted the highest priority; hence it will return a Relay-Request-To-Send (RRTS) message to the source node earlier than the other relays in Rcc at the predefined transmission power of PS−data or transmission rate of RS-data. The remaining nodes in the contending set Rcc will send RRTS messages to the source in the specific order of their priority, as seen in Fig 2. To elaborate a little further, the RRTS message is capable of informing the source about the relay's correct reception and its intention to cooperate. The format of the RRTS frame is the same as that of the RTS frame, which has both a transmitter address field and a receiver address field for the sake of enabling the source to uniquely recognize the different relay nodes.

Step III: Source Accepts Relay for Cooperation:

The source appoints the relay associated with the first correctly received RRTS message as the best relay. Following the elapse of a SIFS interval, the source transmits the Please-Send (PS) message to the best relay at the transmission power of PS-data or at the transmission rate of RS-data, as seen in Fig 2. In order to guarantee that only the best relay node forwards its data message to the destination, we introduce the above mentioned PS message into the legacy IEEE 802.11 MAC protocol, where the format of the PS frame is the same as that of the ACK frame, which includes the receiver's address.

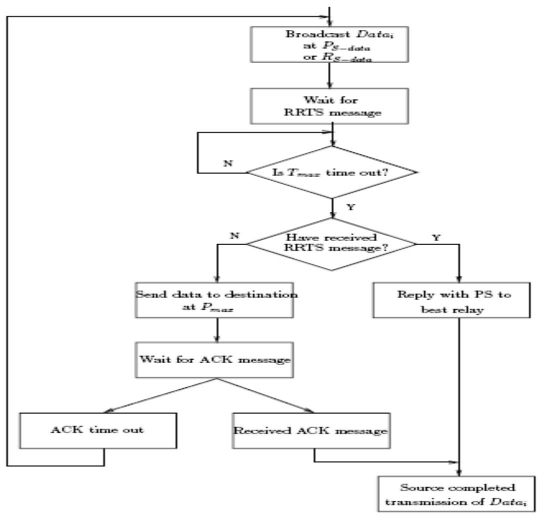

Fig. 3. The flow chart of source retransmission.

Remarks: One of the distinguishing design aspects of our solution w.r.t. the existing literature , is that we allow the source to broadcast its data frame before exchanging control messages, which would be typically required for the best relay selection. If the source only sent a data frame to the best relay after exchanging control messages, the best relay may receive the data frame contaminated by decision errors that leads to a potential loss of the data frame. However, this potential problem is resolved by our proposed scheme, since only the specific nodes, which receive the data frame correctly, will be employed as nodes.

D. *Phase III: Data Forwarding*

If the relay node Ri∈ Rcc received the PS message from the source, it will forward the data frame to the destination at its pre-calculated transmission power of PRi−data after a SIFS period, acting as the best relay, as seen in Fig 2. On the other hand, if none of the relay nodes received the data frame correctly or multiple RRTS messages collided at the source, or alternatively, the RRTS messages are corrupted due to the fading, the source will directly transmit its data frame to the destination at the maximum transmission power of Pmax and the minimum transmission rate of Rmin, as shown in Fig 3. Finally, at the destination, the classic Automatic Repeat request (ARQ) will be initiated, when receiving the forwarded data and then the ACK message is issued in order to reply to the source or the relay. Consider the source’s retransmissions for example in the scenario, when the source does not receive any response from the destination before the timer set for waiting for an ACK message is expired. Then the source will broadcast its data again at PS-data in order to seek cooperation and the procedure described above for relay selection is repeated. The procedure of source retransmission is also characterized in Fig 3, which includes both the relay selection procedure and the source’s direct transmission.

5. CONCLUSION

Cooperative communication is an emerging technology in wireless communications. Exploiting the typical availability of a large number of unused mobile terminals, the research directions proposed will make key contributions to finding desirable cooperation schemes between relaying terminals. These directions are in line with the tremendous efforts in the research community around the world to pave the road for future machine cooperation and communication.

In this paper, an energy-efficient cooperative MAC scheme was proposed, which relies on an autonomous relay selection regime combined with physical layer power / rate control. When compared to the non-cooperative direct transmission regime, the proposed scheme is capable of achieving considerable transmission energy savings and beneficial FER reductions at the cost of introducing a modest MAC overhead, which is at most 8 %, when a 1024-byte data frame is assumed.

6. REFERENCES

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