A Novel Machine-to-Machine Traffic Multiplexing in LTE-A System Using Wireless In-Band Relaying

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Abstract. In Long Term Evolution Advanced (LTE-A) several new features have been added to deal with the ever-increasing demands for higher data rates and spectral efficiency. One of the key features that the Third Generation Partnership Project (3GPP) has introduced is the Relay Node (RN), a low power low cost device used to increase the spectral efficiency, especially at the cell edge. In this paper, we propose to use RNs to address a challenging new problem emerging on the horizon: the expected tsunami of Machine-to-Machine (M2M) traffic in cellular and mobile networks (in LTE, and LTE-A). By taking advantage of RN's low cost, low power, and small size we outline the challenges of and one possible design for using RNs to integrate M2M traffic in LTE-A. To the best of our knowledge, this is a novel idea that has not yet been proposed and may give RNs more longevity and therefore greater value.

Keywords: LTE/LTE-A, Machine-to-Machine (M2M), wireless in-band Relay.

1 Introduction

The cost of using cellular services has fallen dramatically over recent years and cellular broadband connectivity has become globally available. In addition, the ever-decreasing costs and sizes of the devices with integrated sensors, network interfaces, and enhanced power capabilities have led manufacturers to offer a variety of hardware leading to new applications, and services. The term M2M communication denotes these devices, known as machines, which have the capacity to communicate and are expected to vastly outnumber conventional devices [1].

Long Term Evolution (LTE) and LTE-Advanced (LTE-A) are currently considered to be the best candidates to incorporate future technologies such as M2M. M2M applications are expected to have narrowband requirements with infrequent data transmission, but the development of these standards was primarily for broadband data

D. Pesch et al. (Eds.): MONAMI 2013, LNICST 125, pp. 149–158, 2013.

services. With narrowband M2M applications, these existing standards may not achieve spectrum and cost efficiency. Therefore, the integration of M2M communication having low data rates, small packet sizes, and higher number of devices may cause a substantial reduction to the overall performance of future network systems, as shown in [2].

The main goal of this paper is to highlight the challenges of providing M2M services in future mobile networks with an emphasis on LTE-A. In addition, we propose a practical solution for the integration of M2M traffic in the LTE standard. The use of mobile network resources by swarms M2M devices for applications such as remote monitoring can have a significant impact on the performance of regular data traffic such as voice, video and file transfer. This paper illustrates the key M2M issues and challenges for LTE-A radio resource management and proposes a novel solution which leverages RNs to cope with these problems.

2 Machine-to-Machine (M2M)

M2M communication is a rapidly developing research field. The M2M core concept is the interconnection of different devices without human intervention. Due to tremendous growth in this area, the diversity and number of M2M devices as well as the mobile data traffic is expected to grow significantly in the near future [3]. It is also anticipated that the "Internet of Things" will augment the existing Internet with a variety of connected devices [4]. Subsequently, several application domains could benefit from these concepts. Example application areas could be: remote supervision in logistical processes, smart metering and monitoring, intelligent transport system, e-healthcare, etc. Recent advances in research have shown a great interest in remote monitoring of homes, vehicles and places with M2M devices [5,6,7], for example, energy monitoring, traffic surveillance, and environmental monitoring.

Contemporary M2M communications are based on available wireless communication technologies like Global System for Mobile Communications/General Packet Radio Service (GSM/GPRS). At the moment, these standards fulfill the requirements of the existing M2M applications adequately because these technologies offer low-cost deployment of M2M devices with convenient deployment and roaming facilities. However, the expected exponential growth of the M2M traffic and the different new trends and many application scenarios mean that legacy mobile systems like GSM/GPRS will soon be insufficient. It is also worth mentioning that, in contrast to typical end-to-end communications, M2M devices transfer their data without direct human intervention; thus, traffic generated differs from human generated traffic.

3 Relaying in Long Term Evolution Advanced (LTE-A)

The 3GPP has been exploring new ways to increase overall data-rates and to reduce latency. One of the biggest challenges that current mobile communication systems, like LTE, face is low throughput for cell-edge users. The 3GPP has begun studying different techniques to address this problem including: the usage of different low power heterogeneous nodes with the normal micro and macro base stations. These nodes can be femto cells, pico cells, or relay nodes. In this paper, we focus on low cost low power Relay Nodes (RNs). A relay is a device used to extend the cell coverage area [8]. Relaying refers to the communication of the terminal with the network using a node that is wirelessly connected to a donor cell over the LTE air interface [9]. The RN would appear as an ordinary cell to the terminal. The RN is a low-power base station, wirelessly connected to the Donor eNodeB (DeNodeB). RNs also have the capability to improve coverage by simply placing them at locations with poor channel conditions or coverage holes where they perform radio scheduling independently [10]. The protocol stack of a relay is shown in Fig. 1. The 3GPP specifications support both in-band and out-band operations of the relays. The in-band operation means that the link between the DeNodeB and the RN (Un interface) as well as the link between the RN and the terminal (Uu interface) uses the same LTE carrier frequency. In out-band operations; both links have different carrier frequencies. In-band operations can be achieved by time multiplexing the two different links, that is the Un and Uu interfaces. Out-band operations, generally, may not be feasible because they require separate frequency carriers that are scarce resources in the first place. In addition, using isolated antennas for both links to achieve out-band operations would increase the implementation cost and complexity.

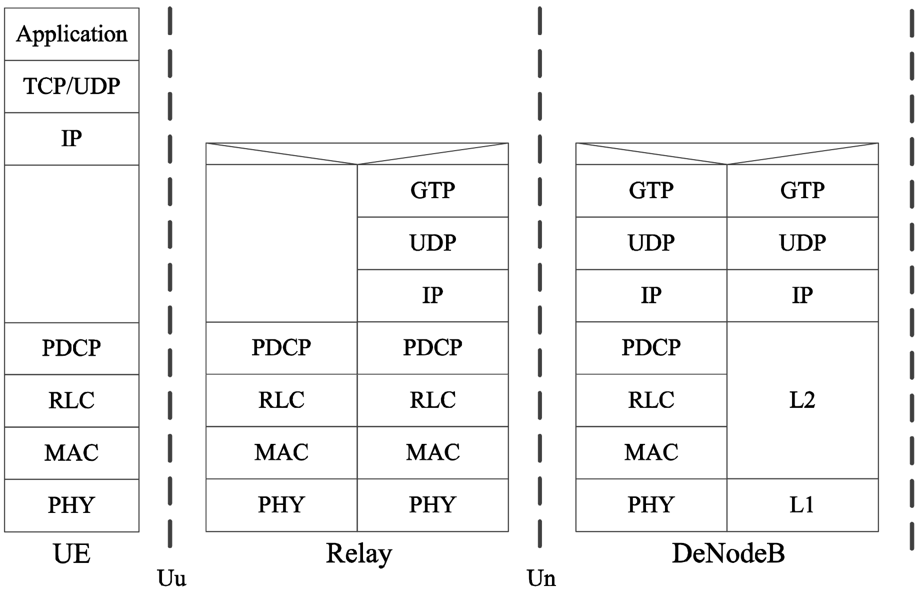

Fig. 1. Relaying system protocol stack

4 State-of-the-Art (SoA)

In the literature on RNs most research efforts are directed towards the implementation aspects and improving system performance. In [11], the performance evaluation of relaying system is achieved using actual deployment environments and propagation models of an urban location in central London instead of employing traditional metrics of artificial environments and models. In [12], the uplink performance of LTE-A with RN deployment is investigated and a resource allocation scheme is proposed to meet the relay requirements. In [13], the authors have performed field trial measurements for indoor relaying with full frequency reuse using a test-bed. The study is extended to outdoor relaying in [14]. Several other works are based on performance evaluation of relaying in LTE-A. Authors of [15] suggest improvements in relaying protocols and frame structure to improve system performance. In [16], the authors propose a user multiplexing scheme for relaying with the aim of reducing multiplexing overhead. The influence of site planning on the performance of relay networks is studied in [17] The system performance enhancement of LTE-A and intercell interference mitigation is shown to be achieved by applying the power control scheme both at the DeNodeBs and the RNs. Out-band relaying operations performance optimization is investigated in [18]. In [19], the reduction in relaying latency is discussed by extending the available relaying schemes. The issue of QoS-aware scheduling for relays with in-band operations is discussed in [20]. The M2M communication over amplify-and-forward relays, also known as repeaters, is discussed in [21]. From our literature review, the facilitation of M2M communication by employing RNs is not a topic under study.

5 Relaying for M2M

In the previous sections, we discussed challenges of M2M communications in the context of future mobile networks. We highlighted some of the latest advanced features of LTE-A that were added to fulfill the requirements for higher data rates and lower latencies. To reiterate, the main reason behind the deployment of the RN architecture in LTE and LTE-A is to increase cell edge users' throughput and delay performance. RNs are designed to be low cost devices that are convenient to deploy in different environment. Figure 2 shows the basic RN architecture. The Un interface is a radio link between the DeNodeB and the RNs. No supplementary hardware is required for link establishment. The RN decodes the received signal in the downlink direction and re-encodes it before forwarding it to the destined terminal [10]. Similarly, in the uplink, signals from the terminals are decoded by the RN and encoded before being sent to the DeNodeB. This helps minimize noise and interference.

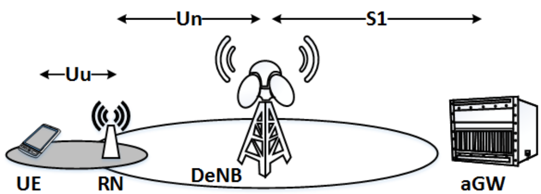

Fig. 2. Relay Node Architecture

The nature of M2M traffic is usually very low data rates; a machine sends a very small number of bits every couple of minutes or hours. Looking at the LTE physical resources and their structure, the 3GPP standardize that the smallest resource unit that the base station can allocate/schedule to a certain LTE users is a Physical Resource Block (PRB). A PRB consists of the aggregation of 12 OFDM sub-carriers, and is capable for transmitting, in favorable channel conditions, several hundred bytes of data. The mobile communication spectrum is a scarce resource of great value and operators pay huge amounts of investment capital to obtain the licenses to operate in a certain spectrum. If an entire PRB is allocated to a single machine a severe degradation in the overall spectrum utilization/efficiency will result. A design change will likely be necessary so that LTE/LTE-A networks are able to incorporate the M2M traffic without affecting the Quality of Service (QoS) of its normal user traffic.

5.1 Possible M2M in LTE-A Integration Solutions

As discussed earlier, the main problem of serving the M2M traffic in LTE network is the inefficiency of the transmission, since each M2M node is going to utilize a full PRB only to send a few bits. There are a number of possible solutions that can be used to increase the efficiency of the M2M transmission:

- Each M2M node can delay the transmission and aggregate a number of its data together before sending it over the LTE network. This can increase the efficiency of the transmission, however the M2M devices normally sends data every couple of minutes or hours and delaying the transmission in order to aggregate several data together will have an impact on the service the M2M node is providing. So this solution may not always be practical.
- The LTE network can schedule M2M devices with less than one PRB, e.g., 1 sub-carrier instead of 12. This means that the 3GPP standard has to be modified in order to reflect this change. In addition, reducing the transmission to a single sub-carrier will also mean that more gap intervals have to be inserted to avoid inter symbol interference that will lead to a reduction of the spectrum. This is not a very practical solution and is also not feasible.
- Several M2M traffic, coming from different nodes, is aggregated and multiplexed together for the transmission over a single PRB. This can be a feasible solution that can solve the aforementioned problems. However, a number of technical challenges must be addressed first before this solution can be implemented in practice. For example, where to aggregate the different M2M traffic? What kind of identification can be used to differentiate between the different multiplexed traffic? The algorithm proposed by this paper falls within this solution category.

5.2 Efficient Relay Node PDCP Algorithm for M2M Traffic Multiplexing

In this paper, we focus on the layer-3 type RNs, where these nodes are used as an Aggregator/Multiplexer entity for the different M2M devices. The wireless in-band RN architecture is probably the most reasonable and cost effective method to be used in conjunction with the M2M traffic. These RNs are low cost devices that can multiplex the different M2M traffic without the use of any additional backhaul. Since these RNs uses the same wireless spectrum that the operator already owns as the backhaul link to the DeNodeB.

In order to incorporate the M2M traffic efficiently in the LTE network, we propose the following functionalities to be implemented in the in-band layer-3 RNs:

- An M2M QoS-aware Relay Node Scheduler (RNS): the RNS is responsible for scheduling the air interface resources over the RN Uu interface. The RNS schedules the transmissions of the different M2M traffic. In order to have efficient M2M transmission, the RNS has to be aware of the different M2M QoS characteristics and correlate this with the varying wireless backhaul of the Un interface between the RN and the DeNodeB.
- An efficient PDCP algorithm in the RN has to be implemented. This algorithm will operates hand-in-hand with the RNS, and will multiplex different uplink data sent by the M2M nodes together to be sent over the Un interface.

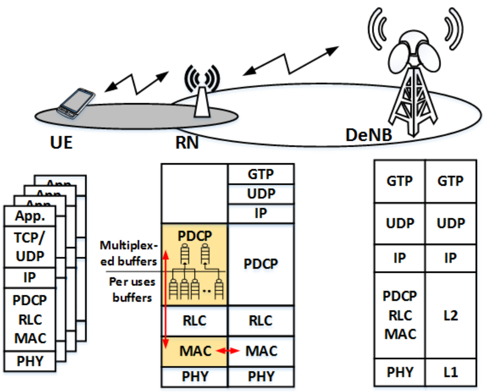

Fig. 3. Proposed RN M2M multiplexing solution

This means that instead of requesting uplink resources from the DeNodeB for individual terminals, the resource request is made by the RN for a group of multiplexed users. This is possible when IP (Internet Protocol) packets of different M2M terminals are multiplexed intelligently into one single large PDCP packet. The DeNodeB would see this as a single radio resource request making it possible to allocate one PRB to several M2M devices and enhance spectral efficiency many folds. Figure 3 shows a high level overview of the proposed scheme.

5.3 Proposal Challenges

The proposed solution can be viewed as aggregating and multiplexing the traffic of several M2M nodes into one packet, similar to what is done currently for several bearers of one user. This RN scheme for M2M communication can be implemented to work only in narrowband so that it fits the requirements of M2M applications and the interference with the signals of DeNodeB is minimized.

Given that the idea is novel, it is not free of challenges and issues. In this subsection a number of research challenges and issues are discussed. One of the main challenges that have to be addressed is the RN Scheduler (RNS) algorithm. As can be seen from the protocol architecture of the RN, it has two MAC layers; one is responsible for the Uu interface towards the RN UEs and one for the Un interface towards the DeNodeB. The RNS is located in the Uu MAC layer; it schedules the access of the M2M devices to the Uu interface. This scheduling is correlated to whatever scheduling grants the DeNodeB is given to the RN, since the RN will ask for uplink transmission by the Un MAC layer. The challenge presents itself in the way the RNS should be designed, i.e., the RNS has to schedule the M2M devices based on their QoS correlating this to the grant given by the DeNodeB for the backhaul transmission. In addition, the multiplexing scheme done at the PDCP layer of the RN is another issue. As stated earlier, several M2M traffic coming from different M2M devices are going to be multiplexed into a single PDCP bearer that will be seen by the DeNodeB by the Un interface. The question still remains, how many multiplexed bearers need to configured? Which M2M traffic should be multiplexed together and in which frequency this should be done?

Since the use of wireless in-band RN seems to be the most feasible option for economical reasons, an additional challenge has to be addressed. Wireless in-band relaying, as it was explained earlier, require a separation between the two different links (Uu and Un), because the RN cannot send and receive at the same time due to self-interference. As a result, the RN has to utilize a Time Division Duplex (TDD) scheme to separate the transmissions of the different interfaces in time. This would imply, that an additional delay is introduced due to the use of the TDD scheme. The RNS has to be designed in such a way that it can balance between the different time slots of the Uu and Un air interfaces. The ratio of split between the two interfaces is far from trivial, and proper investigations and research is required to address the most optimum splitting strategy. Such splitting strategies can either be static or even dynamic depending on the different traffic loads on each wireless interface.

Another very interesting challenge that need to be addressed come from the situation when the RN is also serving regular LTE-A users. The issue here would be that the RNS has to differentiate between the M2M devices and the regular users, and how the RNS can still guarantee the QoS of the regular LTE/LTE-A users since the communication is done over a two hop transmission. Similarly, if the M2M devices are in the range of the DeNodeB but not in the range of the RN, how the DeNodeB should deal with these devices. These challenges are tricky but not impossible to tackle.

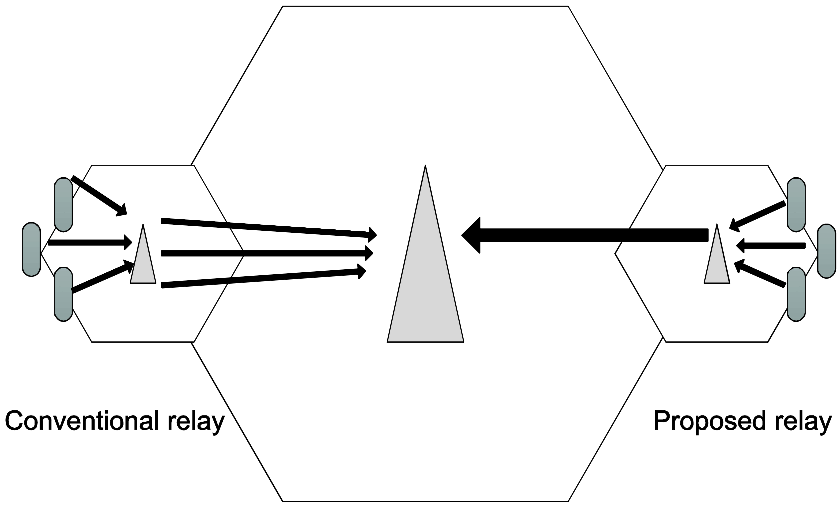

Fig. 4. Relaying schemes

6 Conclusion and Outlook

In this paper we provided an overview of the recently introduced features of the LTE-A system. We focused on Relaying, which is a prominent new feature of LTE-A. The primary aim of relaying is to extend cell coverage and enhance cell edge user performance. We propose to exploit this functionality to facilitate the integration of M2M communication by designing an intelligent RN MAC scheduler and PDCP multiplexing scheme. This proposal would handle the M2M narrowband requirements and boost the spectral efficiency.

In our future work, we plan to implementing an innovative and QoS aware RNS as well as a PDCP multiplexing architecture into our LTE simulation model. The design and implementation of the RN with this special multiplexing capability would help in evaluating the system performance and the impact of the proposed scheme. Finally, we plan to perform several performance evaluations and demonstrate how the proposed solution would help to easily integrate the M2M traffic within the LTE/LTE-A network without any degradation or penalties to the regular network performance.

Acknowledgments. Many thanks to the University of Engineering and Technology, Peshawar, Pakistan and the International Graduate School for Dynamics in Logistics, University of Bremen, Germany for their financial support of this research work.

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