ENERGY EFFICIENT VIDEO TRANSMISSION USING COOPERATION OF LTE AND WLAN

by

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Abstract

Long Term Evolution (LTE) networks are a new generation of networks to meet the increasing demand for multimedia services in wireless networks. Energy efficient data delivery is a key issue in LTE networks. In this thesis, a cooperative mechanism is proposed to decrease the energy consumption in the downlink channel of LTE networks for multicast. In this approach, users in the LTE cell are grouped into clusters based on their distance from the base station. Then, a cluster header is chosen for each group based on a utility function that evaluates user satisfaction after each transmission. Cluster headers receive data directly from the base station and they are responsible to relay data to other users in their cluster using Wireless Local Area Network (WLAN). Simulations show that our approach reduces power consumption of the base station by 5% to 25% compared to conventional multicast transmission mechanism. The cooperative mechanism also helps mobile users to save energy on data receiving.

To my parents and my family

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Chapter 1

Introduction

In this chapter, we briefly introduce multimedia services in *Long Term Evolution* (LTE) networks and explain our motivation to improve resource efficiency for provision of these services. Then, we describe our power saving mechanism to address the resource utilization and summarize the contribution of this research. Finally, the structure for the rest of this thesis is presented.

1.1 Motivation

As mobile network technology moves forward, mobile data and video applications become more and more popular and video will be the dominant form of traffic in wireless networks. Motivated by the increasing need for high data rates and quality of service for video applications, the *3rd Generation Partnership Project* (3GPP) has introduced LTE networks in its Release 8 [1]. Migration from *third generation* (3G) networks to LTE has opened new doors in the wireless network industry and has provided great performance improvements. The LTE technology provides a downlink data rate of up to 150 Megabits per second (Mbps) and in uplink it can provide up to 50 Mbps data rates over a wide area. Achieving these high data rates has enabled cellular wireless networks to support high-speed multimedia applications such as *Voice over Internet Protocol* (VoIP), multimedia streaming and video conferencing [2].

Aligned with these improvements and increased rate of the multimedia services *Evolved Multimedia Broadcast Multicast Service* (MBMS) was introduced to deliver high data rate applications to many users efficiently. LTE standard has improved MBMS by decreasing the

cost and increasing the efficiency and has offered Evolved MBMS (E-MBMS) as one of its multimedia broadband services [1]. It has two data transmission modes. The point-to-point mode is a unicast service that provides a multicast service via multiple unicasts. The point-to-multipoint mode supports a true multicast service. A power counting mechanism is used to decide whether point-to-point or point-to-multipoint consumes less power to transmit data to users in the network [3]. Point-to-point transmission mode may be useful for a small number of users in the cell but it fails dramatically in performance and efficiency when serving a large number of users for which a true multicast service is required.

The dilemma is that multimedia services can not be delivered at any speed. Radio specta available for wireless networks are limited and transmission power, which is the ultimate resource for delivering multimedia services, is highly expensive. On the other hand, user channel condition is time-varying since path loss and multipath fading depend on user position in the network cell that changes as the user moves. Therefore, users in each cell experience different quality of service during delivery of the service. Hence, the radio scheduler plays a fundamental role in assigning radio resources efficiently to users with time-varying channel conditions. The channel condition is computed by the base station using the feedbacks received from users. A unicast scheduler uses channel condition information from each individual user and assigns resources to users with better channel condition. In a multicast session, users receive a multicast stream in one point-to-multipoint transmission. The data rate of the multicast service is constrained by the weakest user channel condition, so that all the users be able to receive it. Assigning resources to users with the worst channel condition in point-to-multipoint transmission mode yields low bandwidth efficiency as well as high power requirements in the downlink channel.

The problem of downlink power minimization in serving multiple multicast groups that have quality of service contraints is known to be NP-hard since the power values vector and *Signal to Interference Noise Ratio* (SINR) values that specify quality of service constraints are correlated [4, 5]. However, approximation solutions and heuristics have been proposed to solve relaxed versions of the problem [4, 5]. In this thesis, the focus is on using cooperative strategies to improve the condition of the multicast group so that it reduces the base station downlink power consumption while providing acceptable SINR levels for all of the users.

1.2   Contribution

In this thesis, we propose a cooperative mechanism to reduce the downlink power consumption in LTE networks. First, a clustering method is applied to divide users into multiple multicast clusters. Then, a cluster header is chosen for each cluster that receives data directly through the LTE interface. Cluster headers are responsible to relay data to users in their cluster using *Wireless Local Area Network* (WLAN). Moreover, they are alternately switched after each transmission to guarantee the fairness of our approach and to motivate users to cooperate.

The most critical part in clustering algorithms is choosing cluster headers. We use a user utility function that demonstrates users' satisfaction. The function is computed for all the users in one cluster. The user with the highest utility value is chosen as the cluster header. Afterwards, resource blocks are assigned to cluster headers based on the scheduling metric used in one of the well-known scheduling algorithms named Proportional Fair [6]. It assigns radio resources to users so as to balance fairness and maximize users' average throughput [6, 7]. For each resource block, the transmission power is set to guarantee the specified SINR level achieved at the receiving end.

In the proposed cooperative mechanism, a cluster header receives data in LTE mode and then relays data to other users in WLAN mode. Previous research [8, 9, 10] shows that the cooperation of LTE or *Wide Metropolitan Area Network* (WMAN) and WLAN can help mobile users save energy and increase their battery life since it is more energy efficient for a mobile user to work in the WLAN mode. More specifically, Liu et al. [8, 9] experimented on the cooperation of WMAN and WLAN and found that this prolongs battery life for both the user and the base station.

To evaluate the performance of the proposed mechanism, we have used an open-source simulator called LTE-Sim which simulates different layers of LTE networks. In order to perform the simulation, multicast transmission is implemented in the LTE network. This requires modification in different layers of the LTE protocol stack. Moreover, a clustering scheduler and a multicast scheduler are implemented in the *Medium Access Control* (MAC) layer. We have also simulated conventional point-to-multipoint and point-to-point MBMS transmission modes that use non-cooperative packet schedulers and compared average downlink power consumption and average packet delay to that achieved by our approach.

Numerical results show that our approach outperforms point-to-multipoint non-cooperative

schedulers in average power consumption and results in a 5% to 25% decrease in downlink power consumption. The point-to-point approach consumes less downlink power compared to our approach; however, the average packet delay achieved is not acceptable for multimedia applications. Our system also achieves lower average packet delay than achieved by the point-to-multipoint approach.

1.3 Thesis Structure

The rest of this thesis is structured as follows. In Chapter 2, background information and previous research in this area are presented. Chapter 3 formulates our problem and proposes our approach for solving it. Experimental results of our approach are provided and analyzed in Chapter 4. Finally, Chapter 5 contains the conclusion of this thesis.

Chapter 2

Background

In this chapter, we will provide some background information about LTE networks. At first, we will present a summary of the features of LTE networks. Then the architecture and main nodes of the physical layer design are presented. Afterwards, MBMS services that are studied in this thesis are introduced. Finally, related work that has been done on the thesis topic is summarized.

2.1 LTE Basics

The rapid growth of IP traffic and data consumption, migration from text-based services to high speed multimedia services (like video sharing, video streaming, and IPTV), and improvements in mobile technology have motivated wireless technology to provide faster and more efficient networks [2, 11, 12].

The *3rd Generation Partnership Project* (3GPP) introduced 3G technology to improve globalization of wireless communication standards. However, 3G networks have only improved over second generation networks in data rate, spectral efficiency, and channel quality. One of the main techonologies that is offered in 3G is called third generation *Universal Mobile Telecommunications System* (UMTS) which uses *Universal Terrestrial Radio Access Network* (UTRAN) and *Global System for Mobile/Enhanced Data rates for GSM Evolution* (GSM/EDGE) radio access network as its main components. UMTS supports bit rates up to 42Mbps and offers both real time and non-real time services (like video conferencing, IPTV, audio, and video streaming support, and high-speed web browsing).

The latest standard for wireless communication networks is LTE, based on GSM/EDGE

and UMTS. Subsequent changes in protocols, frame sizes, and network architectures have improved the performance of this network resulting in lower latency, higher spectral efficiency, and higher capacity compared to its predecessors [13].

2.1.1 LTE Features

In order for LTE to support high speed multimedia services, there have been some changes in the design of the network. We now describe the features of LTE based on the 3GPP specification release 8 [1, 11, 14].

One goal was to achieve higher throughput and lower latency. LTE supports high peak data for 150 Mbps in downlink and 50 Mbps in uplink. The downlink data rate is 3-4 times better and uplink is 2-3 times better than the corresponding rates in UMTS networks. Moreover, the cell edge data rate has also improved with the same deployment configuration. LTE also supports delay sensitive applications such as online gaming and VoIP by reducing the latency of the network. Latency in LTE networks is 20ms compared to 30-40 ms in 3G networks. In addition, network connections and handoffs for mobile devices is sped up to 350 km/h.

LTE is compatible with 3G and non-3G systems and there is continuity between LTE and these networks. LTE also has flexible spectra and can operate in different frequency bandwidths. It allows existing devices to migrate to LTE with different bandwidth capabilities by providing a wide variety of operators. Moreover, LTE provides both paired and unpaired spectra by supporting the same radio technology for *Time Division Duplex* (TDD) and *Frequency Division Duplex* (FDD).

LTE design avoids hierarchy and has a flat architecture. Unlike existing network architectures that use circuit switched systems for voice, LTE is all IP based. It offers E-MBMS to support both voice and multimedia services. It also reduces end user terminal complexity by having multiple access approaches for multicast and unicast transmission mode. As a result, it reduces management and deployment costs and technologies.

2.1.2 LTE Network Architecture

In this section, we briefly describe the LTE architecture in order to better understand how multimedia services are delivered in this network. The overall architecture of LTE consists of two main elements [1, 2, 15]. EPC provides access to external packet networks based on

Internet Protocols (IP). While E-UTRAN manages all radio-interface related functions of the network. In the following, we introduce each of these elements in greater detail.

Evolved Packet Core

The flat architecture of LTE results in one core network that supports all services. EPC is the core network and is designed to reduce latency, achieve higher capacity, and to support all IP-based architecture. It supports not only LTE but also legacy networks including 2G and 3G technologies [11]. EPC consists of four elements [16, 11, 12]: Serving Gateway, Policy and Charging Rules Function, Packet Data Network Gateway, Mobility Management Entity.

Serving Gateway is the termination anchor toward the 3GPP radio interface. It manages mobility of the nodes that move near areas served by different Evolved Node Bs(eNBs). It is also responsible for packet routing, forwarding, and buffering in the downlink.

Quality of Service (QoS) aspects of the network is managed by Policy and Charging Rules Function, the software component of the network architecture. It manages charges and rules on bandwidth, delay, and bit error rate of the flow that is carried by bearers.

Packet Data Network Gateway is the anchor point to packet data networks such as Internet and private IP network. It is responsible for dynamic IP address allocation, rate enforcing, service charge policies, and packet filtering.

All functions related to control plane, subscription, session management, and resource assignment are controlled by Mobility Management Entity. It authorizes and authenticates services by checking authentication vectors received from users. It also handles mobility management functions such as users' location tracking, handover, paging, roaming, and users' access to terminals.

E-UTRAN

As shown in Fig 2.1, E-UTRAN consists of Evolved eNBs that are connected to each other via X2 interface and to EPC using the S1 interface. The eNB is the anchor point between user equipment (UE) and UTRAN in the user and control plane. More precisely, it is connected to mobility management entity in the control plane and to serving gateway in the user plane via S1 interface [1].

One of the main elements of E-UTRAN is eNB that assigns radio resources to users in
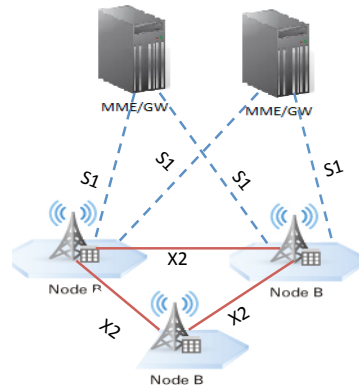
Figure 2.1: LTE Architecture (Adapted from [1])

the downlink and uplink dynamically. It is also responsible for radio bearer control, power control, and connection mobility control [1]. eNB utilizes air channel communication by IP header compression and secures user data by encryption. Furthermore, it forwards the user data to the serving gateway and transmits paging messages to notify users of system changes using physical downlink channel [1].

User Equipment

User Equipment communicates with EPC and E-UTRAN to send and receive data via radio channels. There are different categories of users based on the maximum achievable rate in the uplink and downlink channels [17].

Table 2.1: UE CATEGORIES

Category	Downlink Peak Data Rate(Mbps)	Uplink Peak Data Rate(Mbps)
1	10	5
2	50	25
3	100	50
4	150	50
5	300	75

2.1.3 LTE Downlink Protocol Stack

Downlink packets go through sub layers of LTE protocol stack during their lifetime. In this section, we briefly explain layers of the LTE downlink protocol. The LTE protocol stack is summarized below and is shown in Fig 2.2 [18].

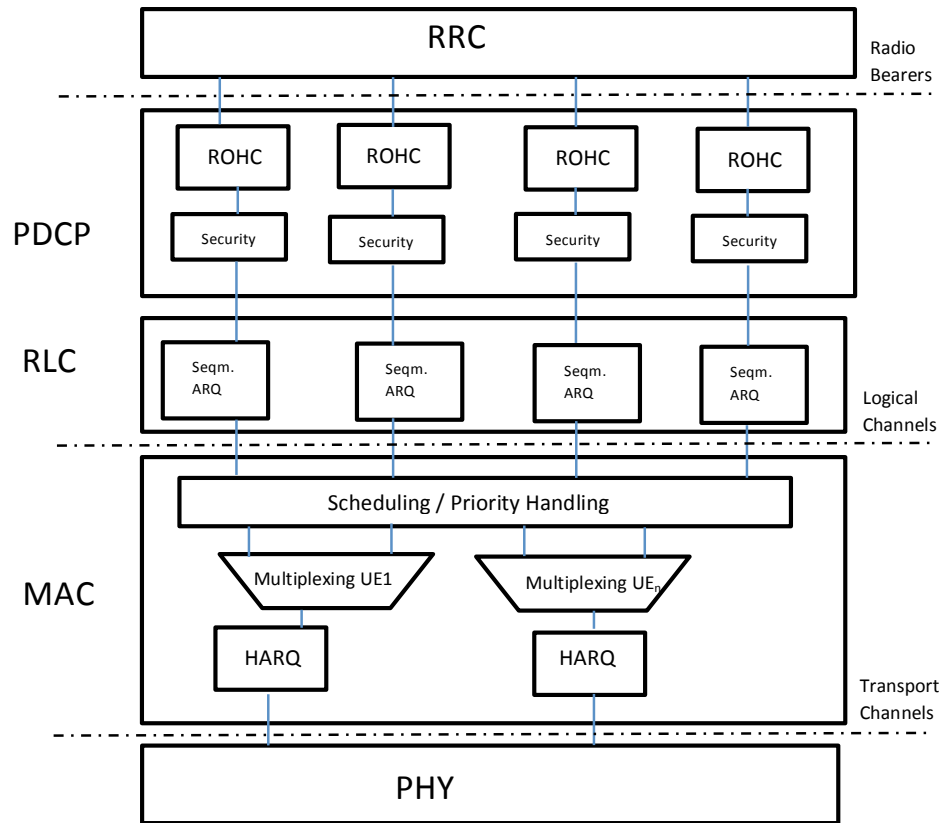Figure 2.2: LTE Protocol Stack (Adapted from [2])

The MAC Layer contains information that was decoded in transport blocks in physical layer through air channels. It is also responsible for formatting the data of transport blocks to logical channels for the higher layers. In addition, error recovery is processed in this layer combined with physical layer and is called *Hybrid Automatic Repeat request* (HARQ). It

retransmits transport block in case of failure.

The RLC Layer performs segmentation and reassembly of the data received from the MAC layer. In the segmentation process, it unpacks the protocol data units and converts them to service data units. The size of protocol data units depends on the channel condition and bandwidth that eNB assigns to UEs in downlink scheduler. It also depends on the size of packet. Large packets are used for video and small packets will be used for VoIP. In addition, RLC uses sequence numbers to guarantee in order delivery of service data units. Out of order packets will be postponed till handover.

RLC operates in three modes depending on the radio bearer setting. Transport mode is used for sending control messages during the initial phase of connection. It effectively sends messages without any header except the RLC header. The HARQ process is applied to data units in acknowledged mode of RLC to recover errors. This mode is used in TCP/IP connections or critical information trasfer. RLC uses unacknowledged mode when there is no time for retransmission due to latency requirements.

The PDCP Layer performs decryption, robust header compression, sequence numbering, and duplicate removal in the user plane. In the control plane, it performs decryption, integrity protection, sequence numbering, and duplicate removal.

Setting up and maintenance of radio bearers happen in the RRC layer. It manages handover decisions based on neighboring cell measurements sent to users and transfers user context from source eNB to target eNB during the handover process. It broadcasts system information and controls user measurement reports such as periodicity of *Channel Quality Indicator* (CQI).

2.1.4   LTE Channels

To transport data across LTE radio interface, different types of channels are used. These channels provide a proper medium for sending data to higher layers based on the LTE protocol stack.

Physical channels transfer user data and control messages in the physical layer. Data transfer service from the physical layer to the MAC layer are provided through transport channels. These channels are defined by the way information is carried, encoding, and modulation of the physical data. Logical channels offer data transfer services from MAC layer and are defined by the type of information they carry. Fig 2.3 shows different types of channels and mapping between them.
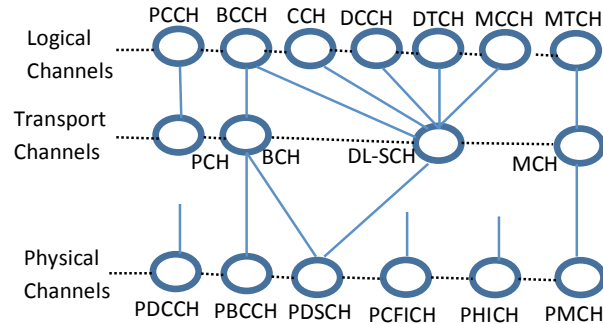
Figure 2.3: Downlink Channel Mapping (Adapted from [2])

2.2 MBMS Services

In this section, we will introduce MBMS, one of the important services offered by LTE.

2.2.1 MBMS Introduction

MBMS has been introduced in 3GPP release 6 to provide better efficiency in delivering high data rate applications [1]. The MBMS architecture is based on packet core domain and is compatible with 2G and 3G technologies.

There are two more nodes in EPS networks that support MBMS. *Multi-Cell/Multicast Coordination Entity* (MCE) is responsible for scheduling radio interface and assigning time and frequency resources in multi cell MBMS sessions. MBMS Gateway (GW) is the entry point for receiving multicast traffic and broadcasts the traffic to all the eNBs in the service area. The *Broadcast/Multicast Service Center* (BM-SC), already presented in 2G and 3G networks, is the entry point for the content provider and transfers the service to end users [14]. MBMS architecture is shown in Fig 2.4.

Based on the type of MBMS service, there are two data transfer protocols. Real-time Transport Protocol/ RTP Control Protocol is used for streaming services. File Delivery over Unidirectional Transport Systems is used for download services. Both of these services run on top of the UDP/IP transport protocol.
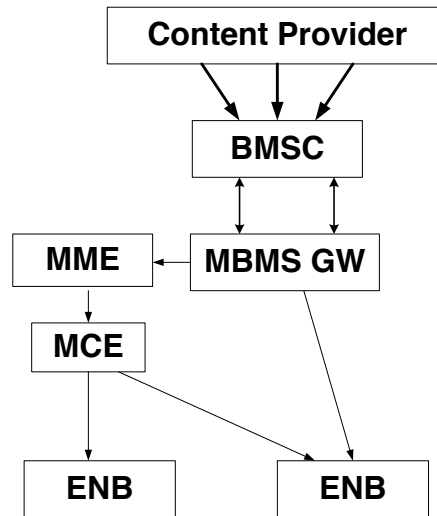
Figure 2.4: MBMS Architecture (Adapted from [14])

2.2.2 MBMS Modes

MBMS has two modes of data transfer: unicast and broadcast. Multicast is a form of broadcast point-to-multipoint data transmission which applies only to a group of users subscribed to the service. In broadcast mode, users are able to share resources and receive data at the same time which is an advantage for resource utilization with a large number of users. Multicast mode is performed in either single-cell transmission or multi-cell transmission.

In single-cell transmission, the MBMS signal is sent over the coverage area of one cell and is delivered within an intra-cell broadcast/multicast transmission. This multicast mode has the disadvantage of significant interference from neighboring cells that reduces the signal-to-noise ratio.

The eNBs in the transmission area should be synchronized and use the same frequency to send the signal in multi-cell transmission. MBMS Single Frequency Network is called MB-SFN and is used for provisioning services such as mobile TV. This transmission mode allows users to recombine signals from different cells and improve signal-to-noise ratio compared to conventional point-to-multipoint transmission. To allow the user to combine received signals from various eNBs, the cyclic prefix is slightly longer.

2.3 Wireless LAN Basics

Wireless LAN provides network access to a group of mobile users using radio resources instead of wired infrastructure so that mobile users have access to network anytime and anywhere without any wired connection.

The most commonly used standard that describes the physical and MAC layers of the WLAN is IEEE 802.11. The physical layer of IEEE 802.11 uses a large number of closely-spaced orthogonal subcarrier signals to carry the data and assigns *Modulation Coding Scheme* (MCS) at a low symbol rate to each subcarrier to achieve data rates similar to single-carrier schemes with the same bandwidth. Different categories of IEEE 802.11 WLAN are explained in the following paragraphs [19].

IEEE 802.11b provides a maximum speed of 11 Mbps that is comparable with Ethernet and its frequency range is 2.4 GHz. The cost of maintenance and deployment is low, but it has the lowest maximum speed. IEEE 802.11b is used in point-to-multipoint transmission mode and its indoor signal range is 30m at 11 Mbps and 90m at 1 Mbps.

IEEE 802.11a supports higher data rates of up to 54 Mbps and its frequency spectrum range is 5 GHz. Due to the frequency increase, it can perform more efficiently in high-load traffic environment. However, because of the pathloss and external wall attenuation, the coverage of the network is decreased. The higher cost of this standard as well as shorter coverage makes it useful only for business environments that need higher data rates.

IEEE 802.11g uses the same frequency range as IEEE 802.11b and is fully compatible with it with a higher maximum speed of up to 54 Mbps. The coverage range for this standard is 32m indoors and 95m outdoors.

IEEE 802.11n improves the bandwidth of IEEE 802.11g. The maximum data rate supported has increased to 600 Mbps using four spatial streams at a channel with 40 MHz frequency. It also offers a power saving mechanism that reduces power consumption using multipath signals only when it increases the performance. The approximate range is 70m indoors and 250m outdoors.

In our cooperation mechanism, we have used IEEE 802.11n in point-to-multipoint transmission mode. It has the largest range among the WLAN standards. Its data rate is also

comparable with LTE downlink which is an important factor in data relay using WLAN in order to send data in an accepted delay. Moreover, it uses power saving mechanisms which is critical for mobile users cooperating in data transmission.

2.4 Related Work

In this thesis, we have studied the problem of downlink power saving in transmission of MBMS data in point-to-multipoint mode. Some of the main approaches we have used include:

- Using cooperation of WLAN and LTE to decrease downlink power consumption

- Using utility function to divide users into clusters

- Frequency selective assignment of resource blocks

This section provides a summary of some of the related studies done in each area. Different well-known packet scheduling algorithms in the 3GPP downlink streaming services are investigated by Ramli, et al. and maximum-largest weighted delay first (M-LWDF) is proven to outperform other approaches in terms of throughput maximization [7]. Moreover, performance of different multicast scheduling algorithms has been studied in MBMS single frequency and single-cell point-to-multipoint modes for both single-layer and multi-layer video transmissions by Barzegar [16]. They have used average user utility that measures the distortion of the signal at the end user and the percentage of users with utility zero to evaluate the performance of the scheduling algorithms. Their results show that single frequency mode has better performance than single cell point-to-multipoint mode for all of the scheduling algorithms.

There are various studies that investigate the problem of maximizing the efficiency in multicast groups by different user requirements. Lu, et al. suggest a *Frequency Domain Packet Scheduler* (FDPS) that focuses on maximizing system throughput by assignment of resource blocks to MBMS users based on the channel condition [20]. In MBMS point-to-multipoint transmission mode, users are treated as a group and transmission rate is dependent on the worst user channel condition. They have proposed a strategy to get the channel state information as feedback and improve the weakest channel condition by focusing on the diversity of frequency-selective fading in resource blocks. Their approach has

made noticeable gains in terms of throughput and coverage compared to blind FDPS that uses static resource allocation. Moreover, Vukadinović, et al. provided a system model to compare the performance of different resource allocation strategies under proportional and fairness constraints [21]. They have also investigated performance of these algorithms for various traffic loads and multicast group sizes. They concluded that an extension of Proportional Fair unicast scheduler is effective in multicast scenario and will meet the fairness and proportional constraints. An adaptive scheduling scheme is also suggested by Liu, et al. that chooses MCS level by considering the available system bandwidth for users with the worst channel condition [22] . Their strategy maximizes the MCS level for the multicast groups and achieves higher cell edge performance compared to previous approaches.

The problem of minimizing the downlink transmission while achieving certain SINR levels has been widely studied. Achieving certain quality of service in links for multiple multicast groups has been investigated by Karipidis, et al. and is proven to be NP-hard [4, 5] . Solutions for some relaxed versions are provided. Salim, et al. have studied different user selection algorithms to minimize the transmission power and found the optimal user selection algorithm for power minimization [6]. They have minimized transmission power while guaranteeing certain data rates for norm-based and angle-based user selection schemes.

The problem of clustering users into multicast groups is studied by Liu, et al. and formulated to achieve a balance between throughput and fairness [23]. They have discussed the problem of user grouping and fixed bandwidth allocation for each of the multicast groups based on a utility function that is computed by users' achievable data rate. Their numerical results show that their approach works optimally for different cell sizes and large scale fading. Recently, Liu, et al. [8, 9], proposed a clustering based approach for video streaming using cooperation of WMAN and WLAN. In this approach, users are grouped into clusters and a header is selected for each cluster. In each transmission cycle, the header of each cluster receives the data of the WMAN burst and forwards it to users within its cluster in the WLAN slot. To guarantee fairness, cluster headers are switched in each transmission slot. Their results proved that the cooperative scheme saves energy of the users as well as the base station.

None of this previous research considered power saving mechanisms using cooperation in LTE networks. In our approach, a clustering mechanism is applied that divides users into clusters based on a utility function. Resource blocks are assigned to users based on channel quality information. Then, power of the resource blocks are set so that certain user

quality requirements are satisfied. Users within each group are served using WLAN. In the following chapters, we will explain the details of our approach and present numerical results that show the benefits of cooperation in saving the downlink power.

Chapter 3

Proposed Cooperative System

In this chapter, we will discuss our cooperative mechanism that is proposed to save power of the base station in LTE networks. We have used a clustered scheduling algorithm that divides users into clusters in each cell and uses cluster headers to relay data to other users in the same cluster using WLAN. As the batteries of users are of critical importance, previous research has suggested mechanisms to save the batteries of mobile users in cooperation mode and verified cooperation benefits both users and the base station [8, 9, 10]. In the following section we describe our approach in fine detail.

3.1   Clustering Mechanism

As was discussed earlier, the transmission rate of a multicast session depends on the worst user channel condition, that is, the throughput of the system will be higher if the worst channel condition is improved. Hence by devising a clustering algorithm we can choose users with better channel condition to be cluster headers and relay the data to the rest of the users within the cluster.

Whenever a service provider sends video bursts at the full rate, it is not guaranteed that all users are capable of receiving it and be feel satisfied at quality of the signal. Increasing the transmission rate raises the cost of the service and makes users more reluctant to subscribe to that service; therefore, the tradeoff between cost and quality of service is of great importance [24].

The goal of the multicast scheduler is to maximize the quality of service received by users with fewer transmission resources. This objective can be achieved by minimizing the

distortion of the channel [16]. In order to find candidates that are responsible as cluster headers, a utility function calculates the distortion level of the video stream in the receiving end and score users based on their channel condition. The utility function of a user can be described as an s-curve [21]. The utility value is a number in the range [0,1]. As this value approaches 1, the distortion of the video stream will be 0. The utility function used in our approach is defined by:

$$u_s(R) = \frac{1 - e^{-C_1(\frac{R}{R_s})^{C_2}}}{1 - e^{-C_1}}$$

where R is the average data rate at which received during the streaming session, R_s is the data rate the video was encoded, and C_1 and C_2 are constants that depend on the video encoder and encoded sequence setting, respectively. In the case of multi-layer stream, the utility function is a staircase in which the number of steps is equal to the number of video layers. However, in the case of fine granularity video coding, the streaming function is an s-curve. Some examples of the utility function with different s-values are shown in Fig 3.1.
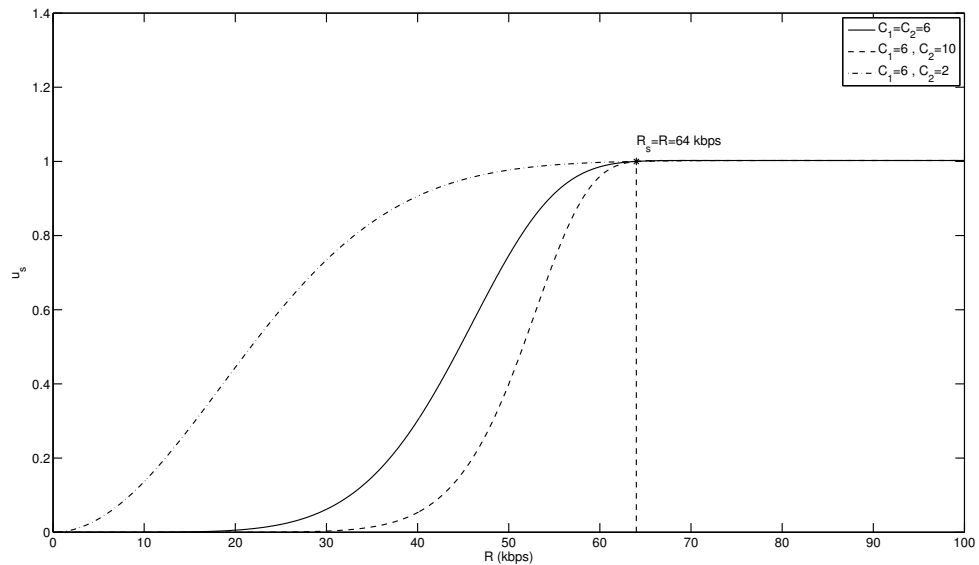

Figure 3.1: Different Forms of Utility Function (Adapted from [21])

To make clustering more efficient and better use the limited range provided by WLAN,

the grouping process has two phases. The first phase happens statically before the data transmission starts. The entire cell is divided into set of concentric tiers, as shown in Fig 3.2, and users in each tier will be considered as one group based on their distance from the base station. Then users in each tier are partitioned into clusters in the second phase of clustering. In each transmission time, the signal-to-noise ratio for each of the users is computed based on the feedback that is sent to the base station. To find cluster headers that are supposed to have better channel conditions, a utility function is defined that takes channel feedback information as input and calculates the average received rate of each user. Afterwards, users with higher utility value will be chosen as cluster headers and users in their WLAN range will be considered to be a cluster. The process ends when each user is either cluster header or belongs to a cluster. Fig 3.3 shows cooperation of nodes in transmission of data.

Assume there are N users $1, 2, \cdots, N$ in the cell which are divided into M concentric tiers. Let R be the radius of the cell.

$$Tier(j) = \left\{ j | d_b^j > R \times j/M \text{ and } d_b^j < R \times (j+1)/M \right\},$$

where d_b^j is the distance from user j to the base station. This is the first phase of the clustering. The algorithm for computing each $Tier(j)$ is given in Algorithm 1.

The utility function used in the clustering phase is defined by:

$$u_i(R) = \frac{1 - e^{-6(\frac{R}{R_s})^6}}{1 - e^{-6}}.$$

After utility values are computed, the user with the maximum value among the users in tier $Tier(j)$, ch_j, and will be the cluster header. Let r be the communication range of a mobile user, users of $Tier(j)$ that are within distance r from ch_j form a cluster:

$$G(ch_j) = \left\{ k | k \text{ uncovered}, |d_b^k - d_b^{ch_j}| < r \right\}.$$

The algorithm for the second phase of clustering is given in Algorithm 2.

To ensure the fairness of our approach, cluster header selection follows a round robin scheme. User i is assigned a number $n(i)$ that specifies how many times that user has been selected as a cluster header. Users that are not selected as cluster header are given priority. If all users have been previously selected, $n(i)$ becomes zero and selection is based only on utility values.
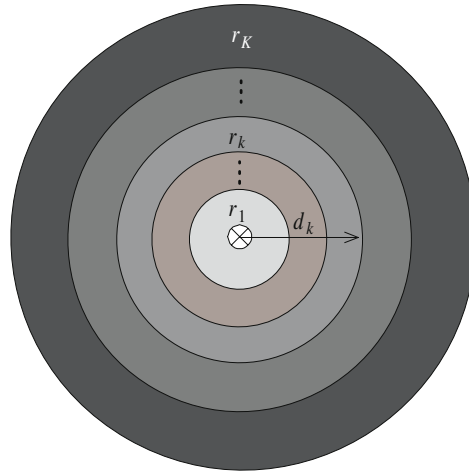
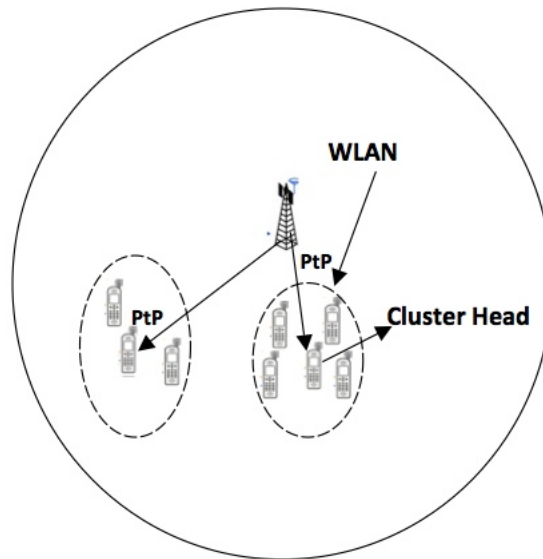Figure 3.2: Dividing Cell into Concentric Tiers

Figure 3.3: Data Transmission in Clustering Mode

Algorithm 1 First Phase of Clustering

---

  for $i = 1$ to N **do**

    for $j = 0$ to M **do**

      Compute d_b^i for node i

      if $d_b^i \geq R \times j/M$ and $d_b^i < R \times (j+1)/M$ **then**

        Add User i to $Tier(j)$

      end if

    end for

  end for

Algorithm 2 Second Phase of Clustering

---

  for $i = 1$ to M **do**

    repeat

      for k in {users of $Tier(j)$} **do**

        Set Max Zero

        Compute $u(k)$

        if $max < u(k)$ **then**

          $max = u(k)$

          $ch_i = k$

        end if

      end for

      for k in {users of $Tier(j)$ } **do**

        if $|d_b^k - d_b^{ch_j}| < r$ **then**

          Add k to $G(ch_j)$

        end if

      end for

    until All nodes are marked

  end for

We use the cooperation protocol proposed by Liu, et. al [8, 9] for data relay within a cluster using WLAN. With the cluster headers chosen, they receive bursts from eNB. Then each cluster header broadcasts a message to all the users in its range and announces that devices should receive data from it. A time-out is set in case the users don't receive

bursts within a certain amount of time. The cluster header in the failed cluster should go through an updating process. After receiving the burst, the cluster headers turn off their LTE interface and broadcast data using only WLAN. After sending, they go to WLAN idle state to save energy. This protocol also handles network dynamics for joining and leaving the cooperative system.

3.2 Scheduling Algorithm

In each transmission slot, packet scheduler should assign resource blocks to users based on a scheduling criteria. One of the goals of scheduling algorithms is to allocate radio resources to users to maximize quality of service for all the users. They aim to maximize throughput while being fair. Two well known scheduling algorithms that meet these criteria are Proportional Fair (PF) and Maximum Rate scheduler [7].

Channel-aware scheduling has been used in LTE networks where users send channel quality information to eNB periodically. CQI feedback is sent by user via uplink control messages and eNB decides how to assign resource blocks to users based on this feedback information [7, 25]. Channel-sensitive scheduling is challenging in multimedia services due to delay constraints on the feedback information arrival.

In our simulations, we have used two different scheduling algorithms. The first is PF [7] which is used for allocation of resources in unicast mode when clustering is applied. The second is Max-Sum multicast scheduler [16, 26] and is used for scheduling resource blocks for multicast groups. In the following, a detailed description of these algorithms is provided.

In PF, at the beginning of each transmission slot, eNB downlink scheduler selects all flows that have to be scheduled in the MAC layer. A flow is chosen at this moment only if it has data to transmit and the receiver is not in idle state. The scheduler computes a scheduling metric for user i and subchannel j and then chooses the flow with the highest metric to schedule for each subchannel. The process has the following steps:

In the first step, eNB creates a list of flows that has to be scheduled for the subframe. For each flow, CQI feedback is stored and MAC queue length that shows the amount of data to transmit. The scheduling metric is then computed. The PF scheduler metric considers channel quality experienced by each user and also past user throughput. The goal of the PF scheduler is to maximize throughput, while providing fairness among users. The metric used is based on the available data rate and average past data rate. The weight of flow i in
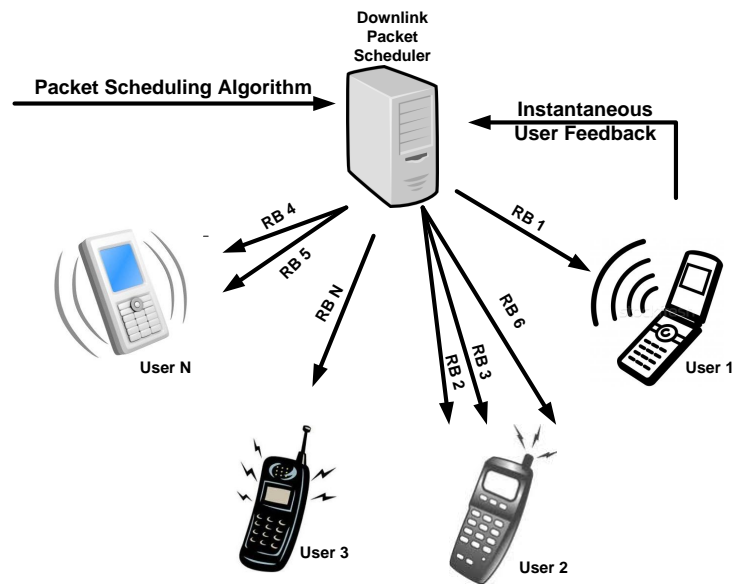
Figure 3.4: Generalized Model of Downlink Packet Scheduler (Adapted from [7])

the subchannel j is computed by

$$W_{ij} = r_{ij}/R_i.$$

The value r_{ij} is calculated based on the user feedback that is sent to eNB for subchannel j periodically. The average transmission rate R_i is computed by:

$$R_i(t) = \left(1 - \frac{1}{t_c}\right) \times R_i(t-1) + \frac{1}{t_c} \times r_i(t-1)$$

where t_c is time window of appropriate size. This window size is a tradeoff between user satisfaction and throughput maximization.

The eNB assigns subchannel j to the user with the highest metric. The size of transport block to be transmitted is then computed based on mapping the CQI index to MCS index and number of assigned subchannels to the flow.

Max-Sum scheduler is an extension of the PF scheduler and is proposed for LTE and HSDPA networks. Its objective is to maximize the product of users' utilities within a multicast group. The objective function of the scheduler is given by:

$$\varphi(n) = \prod_{m=1}^{M} \prod_{S=1}^{S_m} u(m,s).$$

The scheduler decides multicast group, transmission rate, and MCS index in each transmission slot. In order to make decisions, the scheduler should have channel feedback information from users in each subcarrier periodically. It's not possible for users to send feedback information continuously. Therefore, users send SINR values of each subcarrier periodically and eNB uses the average throughput of users in each *Transmission Time Interval*(TTI) [16, 26]. The details of the Max-Sum scheduler are presented below [16, 26]:

In the first step, the scheduler decides the highest transmission rate and the best modulation coding scheme for each multicast group. The transmission rate for each group and each layer of the video stream in time slot n is calculated by:

$$R_{MCS} = PRB_{\text{full rate}} \times \text{OFDM symbol per subframe} \times \text{bit per symbol} \times \text{code rate}.$$

In this step, MCS index is the maximum value of

$$MCS^*_{k,n}(m) = \text{argmax}_{1 \leq MCS_{\text{index}} \leq 15} \left\{ \sum_{S=1}^{S_m} u_n^k(m,s) \cdot R_{MCS} \right\}.$$

The second step selects the layer of the video stream that maximizes the product of users' utilities per multicast group.

$$k_n(m)^* = \text{argmax}_{1 \leq k \leq L} \left\{ \sum_{s=1}^{S_m} u_n^k(m,s) \cdot R_{MCS}^* \right\}.$$

The final step is choosing the multicast group that has the highest product of user utility values with the transmission rate and video layer decided in previous steps.

$$m_n^* = \text{argmax}_{1 \leq m \leq M} \left\{ \sum_{s=1}^{S_m} u_n^{k^*}(m,s) \cdot R_{MCS}^* \right\}.$$

The Max-Sum algorithm is designed for scalable video transmission but in our approach the video stream is not layered.

3.3   Base Station Power Setting

In cellular networks, power control mechanisms are applied to increase network capacity and coverage while maximizing output signal power and decreasing power consumption. These strategies are used for the base station power setting in the downlink and for mobile station power control in the uplink.

In LTE, there is open and closed loop power control for the uplink. In open loop power control, the mobile station sets the power level of the signal based on the power of the noise and the desired level of SINR for the received signal. Closed loop power control uses the power level computed by the open loop power control as an input and adjusts the power level of the signal based on the path loss experienced by each user. However, there is no power control for the downlink in LTE and the base station uses its maximum power to guarantee the quality of the signal at the receiving end [27].

There are two different ways to set the power of subchannels in the downlink. In the conventional method, fixed power is set for the base station and divided equally among subchannels without considering channel quality information. In the waterfilling method, more power is allocated to subchannels that have better channel quality; therefore, the sum of the data rates of the subchannels is maximized. The power allocated to each subchannel

is related to the data rate. The data rate is related to signal-to-noise ratio logarithmically based on the Shannon capacity formula given by (3.1) [28].

$$\text{data-rate} := \frac{1}{2} \times (1 + \log SNR).$$ (3.1)

The problem is then formulated as:

$$R_{max} = \sum_{i=1}^{N} \sum_{j=1}^{M} w_{ij} R_{ij}$$

subject to

$$\sum_{i=1}^{N} p_i < P_{total}$$

where w_{ik} is the binary channel allocation index of user i and subcarrier k satisfying $w_{ik} \in \{0, 1\}$ and $w_{ik} \leq 1$. w_{ik} is 1 if subcarrier k is fully occupied by user i or 0 otherwise. P_{total} is the maximum power at the transmitter in the downlink.

In our approach, there is no fixed power setting for the base station. In each TTI, power is assigned to subchannels based on the CQI feedback received from users. Certain quality of the received signal is set for all users in terms of $SINR_{target}$. Transmission power is then computed by calculating interference and pathloss for the specified channel realization model. The power of the base station is then set to be the sum of the values set for the subchannels. The formula for the power computation for each subchannel is given by:

$$SINR_{target} = \frac{P_{received}}{noise + interference},$$

$$P_{transmission} = P_{received} * \text{ PropagationLoss(rb)},$$

$$P_{transmission}(rb_i) = SINR_{target} + \text{noise} + \text{interference} - \text{PropagationLoss}(rb_i)|\text{db format}$$

subject to :

$$\sum_{1}^{N} power(rb_i) < \text{max-power of BS}.$$

The advantage of setting the power dynamically is that since the power is set based on specific quality requirements of the user, it guarantees receiver signal quality and also decreases power consumption of the base station.

Chapter 4

Simulation

In this chapter, we provide numerical results showing that the proposed cooperative system outperforms previous non-cooperative schedulers in average power consumption and average delay. First, parameters used in the simulation and simulation methodology are described. Then experimental results are presented. Finally, results are analyzed based on the theory provided in the previous chapters.

4.1 Simulation Procedure

To simulate the scenarios in the LTE network, we have used an open-source simulator called LTE-Sim 2.1. LTE-Sim is an open source C++ simulator that simulates different aspects of LTE's main elements. LTE-Sim simulates QoS management, single cell/multicell scenarios, multiuser environment, handover, frequency reuse techniques, and user mobility. It also implements well-known scheduling algorithms including Proportional Fair and Modified Largest Weighted Delay First, and Exponential Proportional Fair. Moreover, in the application layer different traffic generators are implemented including trace-based, VoIP, constant bit rate, and variable bit rate. Simulation of multicast sessions needs some modification in different layers of the LTE protocol stack. In the application layer, we have implemented the MBMS traffic in point-to-multipoint mode. In the MAC layer, two schedulers are added: One is used in the clustering mechanism and the other supports resource allocation in point-to-multipoint transmission mode. For the point-to-point mode, we have used Proportional Fair scheduler provided by LTE-Sim. In addition, eNB power setting is done in the physical layer. The power values are computed in the MAC layer and are passed

to eNB's physical channel so that the power values for each subchannel are set in each TTI. In the clustering mechanism simulation, the receiving end should only receive packets when it's a cluster header, otherwise it is called a WLAN node. Therefore, the physical layer of the receiving end has been changed. Due to the complexities of the LTE network simulation, the simulation of the WLAN part is skipped in our evaluation.

Before the simulation starts, the first phase of clustering is applied and users are divided into tiers based on their distance from the base station. Considering the IEEE 802.11n coverage range and the radius of the cell, the number of tiers in the simulation is assumed to be $M = 5$. In the MBMS traffic generator, a radio bearer is assigned to users of each tier. Then the MBMS data transmitter starts the downlink scheduler.

In each TTI, radio bearers that have data to transmit are added to the list of the scheduler. The second phase of clustering is then applied for all the radio bearers in the list. To that aim, utility values of all the users in the radio bearers are computed and the user with the maximum value is chosen to be the cluster header. After the clustering phase is done, resource allocation starts. The scheduling metric is computed for each of the cluster headers and resource blocks are assigned to the user with the highest metric. Afterwards, the data rate, modulation coding scheme and transport block size are calculated to start data transmission. For each cluster header, the CQI feedback of the allocated resource blocks is mapped to the SINR values based on table 4.1 and effective SINR is computed using formula 4.1. Then, SINR values are mapped to MCS index and transport block size is calculated using the MCS index and the number of resource blocks assigned to the cluster header flow. Before transmission starts, the values of downlink power for each of the subchannels are computed. As discussed in the previous chapter, the power values for each resource block are computed using the SINR values of the cluster head assigned to that block, the path loss experienced by the user, noise and interference experienced in that block. This transport block size is sent to the RLC layer which is set in unacknowledged mode to compute packet size. The power values are also passed to the physical layer for when the transmission signal starts sending the packets.

$$\text{SINR}_{\text{effective}} = \frac{\sum_{i=1}^{N_{rb}} \text{SINR}_i}{N_{rb}} \tag{4.1}$$

On the receiving end, users send their CQI feedback using full-band periodic reporting mode, with the reporting interval set to 1ms. Whenever a user receives a signal, it first

Table 4.1: CQI TO SINR MAPPING

CQI Level	SINR(db)
1	-4.63
2	-2.6
3	-0.12
4	2.26
5	4.73
6	7.53
7	8.67
8	11.32
9	14.24
10	15.21
13	18.63
14	28.49
15	34.6

checks to see if it's a cluster header. If not, it forwards the packet, otherwise it computes SINR of the received signal. If the measured SINR is less than the SINR target, the user drops the packet, otherwise, it will receive the packet.

4.2   Simulation Parameters

This section includes the description of the parameters used in our simulation.

SINR Calculation: SINR value for the received signal of the i-th user in the j-th subchannel is computed by:

$$\text{SINR}_{ij} = \frac{\text{PRX}_{ij}}{FN_0B + I}$$

where PRX_{ij} is the receiving power of the i-th user in the j-th subchannel, F is the noise figure (with default value 2.5), N_0 is the noise spectral density (with default value $-174db$), B is the bandwidth of the resource block ($180MB$) and I is the interference. The interference is the total power of eNBs sharing the same frequency.

Propagation Loss Model: LTE-Sim has simulated propagation loss for different channel realization models. In order to compute propagation loss, it needs to calculate the shadowing effect, the penetration loss, the path loss, and the fast fading effect due to signal multipath. Let PTX_j and PRX_{ij} be the eNB transmission power and the reception power of the i-th user for the j-th subchannel, respectively. PRX_{ij} is given by:

$$\text{PRX}_{ij}|\text{dB} = (\text{PTX}_j - M_{ij} - \text{PL}_i - \text{PN}_i - \text{SH}_{ij})\,|\text{dB}$$

where M_{ij}, PL_i, PN_i, and SH_{ij} are the losses due to multipath, path loss, penetration, and shadowing, respectively. In our simulation, we have used the macro cell urban areas channel realization model. According to 3GPP standard [1], the path loss model for urban area is computed by:

$$L = I + 37.6 \times log_{10}(R)$$

where I is 128.1 at 2GHz and $R(km)$ is the distance between two nodes.

LTE Frame Structure: LTE-Sim has simulated both the TDD and the FDD frame structures of LTE. In FDD mode, the frame is divided into two halves. The first half is used for the uplink and the second half is used for the downlink transmission. In TDD mode, the frame is divided to two subframes each lasting 5ms similarly to FDD but in each half a subframe is reserved for special purposes and not used for data transmission. In our simulation, we have used the TDD mode for the frame structure.

Channel Model: LTE uses different channel models including Pedestrian and Vehicular A and B that show low, medium, and high delay spread environments. The channel model used in our simulation is the Pedestrian A channel. Its delay per channel power is presented in table 4.2 for different power values.

User Mobility: Two types of mobility models are supported by LTE-Sim: Random Direction and Random Walk. In the first model, a user randomly chooses speed and direction and moves in that direction until it reaches the cell boundary and then it chooses another direction. In the second model, a user randomly chooses speed and direction and moves in that direction for a given distance. It changes direction after it reaches either the given distance or the cell boundary. In our simulation, we have used the Random Direction model

Table 4.2: PEDESTRIAN A CHANNEL MODEL

Relative Delay(ns)	Relative Power(db)
0	0
30	-1
70	-2
80	-3
110	-8
190	-17.2
410	-20.8

that updates the user position in each TTI.

4.3   Simulation Scenario

To analyze the behavior of the clustering algorithm, different scenarios have been imple-
mented. In the first scenario, the clustered scheduling algorithm is applied and downlink
power is set so that it meets the quality constraints of each subchannel. In the second sce-
nario, point-to-multipoint mode of MBMS is simulated and Max-Sum scheduler is applied.
No power setting method is used in this scenario and the power of downlink is equally di-
vided between subchannels. In the last scenario, the point-to-point transmission mode of
the MBMS is simulated. The Proportional Fair scheduler is used and the power of downlink
is divided equality between subchannels without considering channel quality information.

The network topology is simulated as a multi-cell multiuser environment. It consists of
six hexagonal cells that form on the edges of a cell in the center and users are randomly
distributed in the central cell. The user mobility model is based on the models described in
Section 4.2.

Each simulation scenario takes $20ms$ to run. However, as each case is run for user
populations ranging from 1 to 100 users while averaging the result of 100 runs per user
population to eliminate the effect of randomness in user distribution, the entire simulation
takes a long time to run. Therefore, we have used a super computer to parallelize the
running script to obtain the results more quickly (approximately 0.1 required time in a PC
that has 2.7-GHz intel core with 4GB RAM). We have used Hermes cluster that is an IBM
iDataplex server with eight 2.67-GHz Xeon x5550 cores with 24 GB of RAM. Hermes has
82 nodes with each node having eight cores making 656 cores available. One job is assigned

to each node running three different simulation scenarios for a specific user population. The parallelized script submitted each run of the simulation as a job to one of the cores of Hermes. The total running time on the Hermes server was approximately 10 hours, which includes the waiting time of the jobs in the queues.

Simulation setting are presented in Table 4.3.

Table 4.3: SIMULATION PARAMETERS

Parameters	Value
Cellular Layout	7 hexagonal grid cells
Cell Radius	1 Km
Maximum BS Tx power	43 W
Background Noise	-174 db
Channel Bandwidth	10MHz
Propagation Model	Okumura Hata
SINR Target	5 db
Users Distribution	Random Distribution
Wireless Range	100 m (802.11n)
Number of Tiers	5

4.4   Experimental Results and Analysis

To evaluate the performance of our cooperative approach, two metrics are used: average downlink power and average delay of packets during the simulation time. The data collected as a result of the simulation is presented in Fig. 4.1. This data is dependent on the distribution of the users in the cell, which affects the clustering procedure, and users' distance from the base station. After finding the cluster header, the number of users forming a cluster depends on users' distribution. The distance of users also has an impact on their channel condition and the utility value of users will differ in different scenarios. To achieve reliable results and control these parameters, in each simulation run the users' location is fixed for the point-to-point, point-to-multipoint, and clustering approaches. To eliminate the influence of random user distribution, each simulation is run 100 times for each user
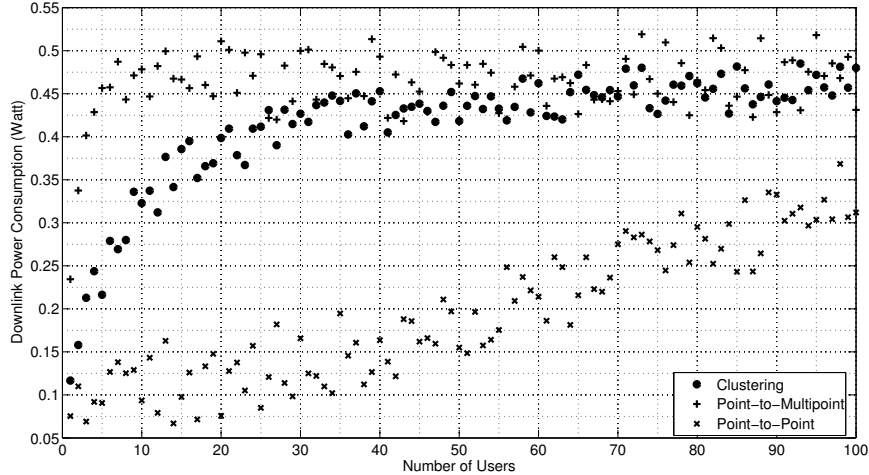
Figure 4.1: Simulation of Downlink Power Consumption Data

population and the average of the results are reported. Since the data is a set of individual points, a curve is fitted to the data collected in each scenario using MATLAB's Curve Fitting Toolbox (`cftool`). It finds the trend in the data and helps to better analyze and compare the behavior of the three approaches. A rational function with linear numerator and denominator is fitted to the clustering and point-to-multipoint simulation data with $R^2 > 0.90$ which shows the approximation percentage of the curve fitting procedure. As the power of the base station increases with the number of the users in the point-to-point scenario, a rational function with a quadratic numerator and a linear denominator is fitted to the simulation data with $R^2 > 0.90$.

Fig. 4.2 shows the trend of the downlink power consumption for three different scenarios described in Section 4.3. The point-to-point approach outperforms the multicast approach and our clustering approach is better than the conventional point-to-multipoint method. The point-to-point approach performs better since in in each TTI, the PF scheduler assigns resource blocks to users that have higher scheduling metric and worse users will wait until their channel condition improves. Therefore, the power needed to reach the SINR_{target} level at the receiving end is less than the other two schedulers. However, a flaw in the point-to-point approach is shown in the next figure that depicts the average delay of packets. In the clustered scheduler, we have improved the worst user of the multicast group by choosing the user with highest utility value as the cluster header. Therefore, the scheduler
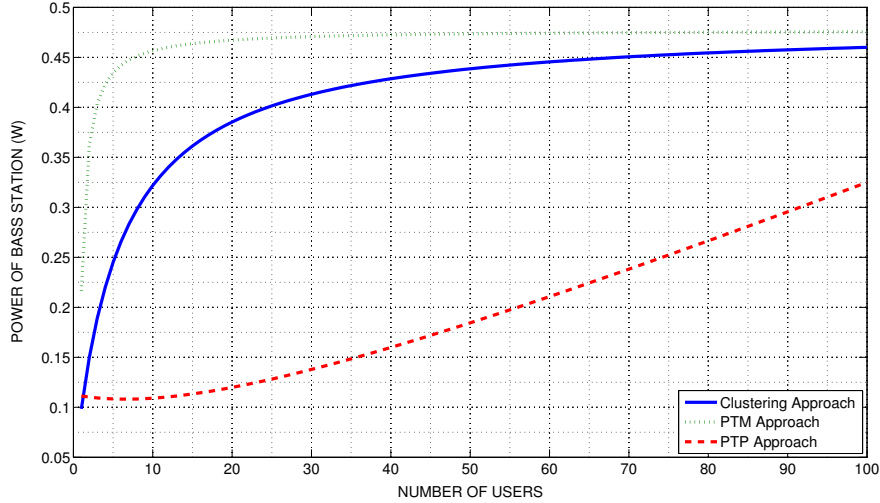
Figure 4.2: Average Downlink Power Consumption

is responsible to allocate the resources to cluster headers that have better channel quality and the power needed for downlink transmission to achieve SINR_{target} is decreased compared to the conventional point-to-multipoint approach. Fig. 4.2 shows that our approach saves the downlink power of eNB about 25% on average for a user population of less than 20, about 15% on average for a user population between 20 and 50, and about 5% on average for a user population between 50 and 100. As the number of users grows, the cooperative mechanism leads to less power saving. This is mainly because a larger number of users call for more cluster headers which makes each of the cluster headers less likely to be able to improve the channel condition of the multicast group. Therefore, power consumption of the downlink is improved less in larger user groups. Both approaches behave logarithmically and achieve a maximum bound as the number of users increases while the point-to-point approach grows linearly as number of the users increases.

Fig. 4.3 shows the trend of the average delay during the simulation time for each of the scenarios. The delay of clustering and point-to-multipoint approach is negligible compared to point-to-point delay. Fig. 4.4 compares the average delay of the clustering approach to that of the point-to-multipoint approach and shows that delay decreases in the clustering approach. This is because the number of users served by an eNB is decreased which means there are more resources available for cluster headers. Therefore, data rate and transport block size is increased and delay is decreased.
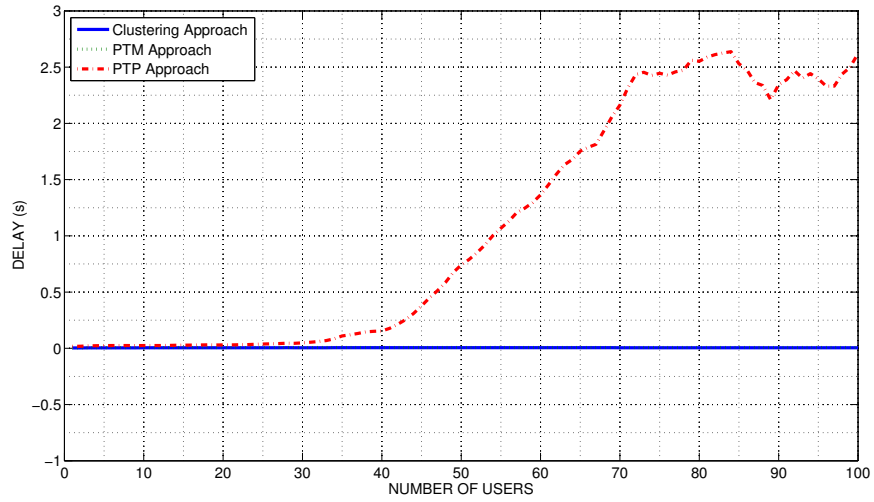
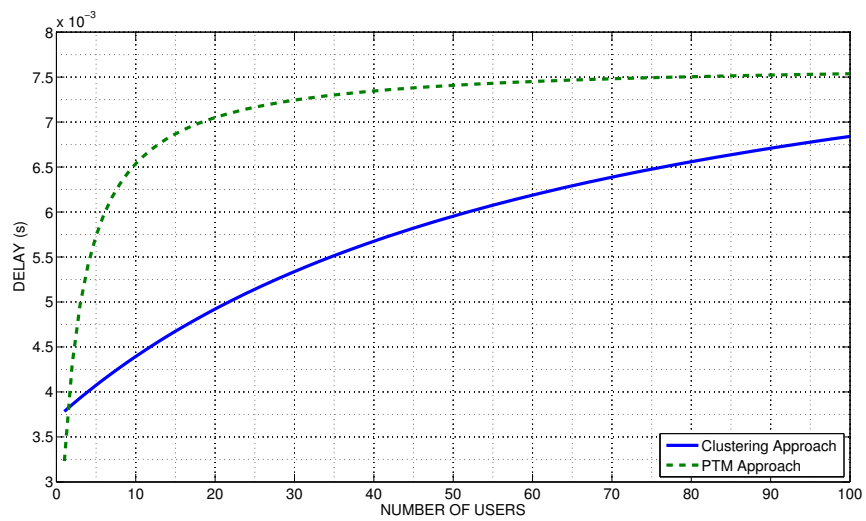Figure 4.3: Average Packet Delay

Figure 4.4: Average Packet Delay for clustering and PTM approach

In the cooperative approach, users act as WiFi routers while connecting to the LTE network. Therefore, battery drainage of the mobile station is a critical issue that has to be investigated. Liu, et al. presented numerical results that shows cooperation benefits both mobile users and the base station in WMAN [8, 9]. They have used idle and connected modes to switch between WLAN and WMAN interfaces in transfer intervals and make users sleep, when there is no data transfer.

Keshav, et al. proposed a power saving mechanism similar to Liu, et al. [8, 9] that takes care of the issue arises in coordination of LTE and WLAN [10]. LTE has power control mechanisms in the uplink that saves the battery of users significantly using connected discontinuous reception (DRX) strategies. WiFi also has many power saving strategies. Therefore, in order for these networks to cooperate efficiently, these power saving strategies must be combined.

Keshav, et al. have used two mechanisms of power saving. First, whenever there is no data transmission interfaces go to sleep and wake up only to receive paging or incoming information. The second mechanism is to find the DRX pattern of the LTE and let mobile users go to sleep whenever there is a gap in the data transfer. Their approach offers a power saving mechanism for the users in cooperative LTE/WLAN networks and solves high power consumption of users while cooperating [10].

Chapter 5

Conclusion and Future Work

Cooperation of wireless networks improves capacity, performance, and coverage of these networks. In this thesis, we have studied a cooperation scheme of the LTE and WLAN networks and investigated its benefit in reducing power consumption of the downlink channel in LTE networks while previous research show that cooperation saves battery of the mobile users. In the following, a summary of the contributions of this thesis and some future work in this direction are presented.

5.1 Contribution Summary

In this thesis, we have proposed a mechanism for cooperation of LTE and WLAN networks. A clustering algorithm is devised to group users into clusters. A power setting mechanism is also presented to set transmission power of downlink subchannels based on the required quality of service at the end users. Moreover, some modules are added to an open source simulator called "LTE-Sim" to simulate the clustering scenario and evaluate average power consumption of the downlink channel in clustered, point-to-point, and point-to-multipoint transmission modes. Results of the simulations show that our approach consumes less power than a conventional point-to-multipoint transmission mechanism. The point-to-point approach outperforms our approach and uses less downlink power. To compare the performance of our approach, we have measured average packet delay in each transmission. Results show that the average delay is not acceptable for large numbers of users in point-to-point transmission mode. Therefore, clustering algorithm performs more efficiently in multimedia applications that are delay sensitive.

5.2 Future Work

Our research has fully investigated the cooperation of LTE and WLAN networks. However, there are still many aspects that have to be considered to benefit from cooperation mechanisms.

The WLAN simulation of mobile users in the proposed mechanism is an interesting topic. Simulating the IEEE 802.11n WLAN protocol in multicast transmission mode will give a more precise evaluation of performance metrics of the proposed cooperative system.

New modules have to be added to LTE-Sim, so that mobile users can send data to each other.

Studying battery life improvement mechanisms for mobile users in our cooperative mechanism is also a valuable research topic.

This thesis focuses on cooperation in single cell point-to-multipoint mode. The single frequency network mode of MBMS that reduces SINR significantly should be investigated.

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