Shared Segmented Upload in Mobile Networks using Coordinated Multipoint

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Abstract

Long Term Evolution Advanced (LTE-Advanced) networks have problems of low data rate for cell-edge users, as well as coverage gaps. Contemporary communication standards use different techniques to deal with these problems; one candidate technique is called Coordinated Multi-Point (CoMP). In this context, we introduce Shared Segmented Upload (SSU), a novel method for uploading large files from a UE to multiple BSs in a CoMP communication scenario. We use the Discrete Event System Specification (DEVS) formalism to model a mobile network using two approaches: SSU and a conventional non-cooperative algorithm. The simulation results show that, compared to the conventional method, the SSU algorithm improves cell edge users' uplink performance and reduces the latency for a User Equipment (UE) to upload its data to the network.

1. Introduction

Since the advent of first generation mobile networks for commercial usage in 1978, the rate of adoption of mobile devices has grown exponentially. In 2013, the number of mobile subscriptions reached 6.8 billion [1]. This is equivalent to 95% percent of the world population. Furthermore, in recent years, mobile networks have impacted the way in which internet users choose to access the internet. Statistics show that, between May 2011 and May 2012, the proportion of global web page views from mobile devices almost doubled [2]. Many of those mobile web users use smart phones as their primary way to access the web. Consequently, service providers are confronted with two challenges: the large numbers of user equipment (UE) that they need to support, and their high data rate demands.

There are ongoing efforts to improve mobile networks performance to deal with these two problems. We can divide these efforts into three major categories: improving efficiency of the current resources, providing new hardware, and introducing new standards. In terms of standards, telecommunication service providers focus on the required quality of service for their users and on increasing the network performance by using more efficient algorithms and techniques. One of the mobile communication standards that have been introduced by the 3rd Generation Partnership Project (3GPP) is the Long Term Evolution Advanced (LTE-Advanced). This standard is a backward-compatible enhancement of the LTE standard for the Fourth Generation (4G) cellular systems [3]. LTE-Advanced (LTE-A) meets or exceeds the International Mobile Telecommunication (IMT)-Advanced requirements and is considered as a candidate for IMT-Advanced systems [4, 5, 6].

One of the objectives of LTE-A networks is to provide consistent services for the UEs regardless of their location. Considering the ever increasing user demands for higher data rate, poor network service is not acceptable. However, providing high quality signals to UEs in all coverage areas is challenging; especially when a UE is located near a cell border. This group of users suffers from two problems: the long distance from the cell center where their serving Base Station (BS) is located, and the higher interference from the neighboring cells. Service providers require that these problems be addressed to meet the expectations of cell edge users. To do so, a mobile network standard such as LTE-A can use different techniques, such as Coordinated Multi-Point (CoMP). CoMP coordinates the BSs to decrease the interference and increase the received signal power. This method also increases the quality of the services for cell edge users.

We propose a new algorithm, called Shared Segmented Upload (SSU), for uploading large files from a UE to multiple BSs in a distributed CoMP architecture. The algorithm has common points with the BitTorrent protocol [7], which is used to speed up the download of large files on the internet. BitTorrent allows users to join a swarm of hosts to download and upload from each other, simultaneously. BitTorrent is an alternative to the single source, multiple mirror sources technique for distributing data, and can work over networks with lower bandwidth. We adapted this technique to improve data upload from an UE to a set of BSs. This technique can solve the bottlenecks caused, for instance, by users uploading large files from the UE to the network, improving the upload performance and quality. This technique can be considered as a subset of the Joint Processing method in CoMP. The bottom-line is to transfer large files in small segments from a single UE to the BSs in a coordination set. This process allows for faster and more efficient transfer of a file, since file segments are transferred independently, which allows for dynamic adjustment of the data flow, in which BSs with stronger reception receive more segments. Eventually, the collected segments are gathered and organized in the serving BS, like the pieces of a puzzle.

In order to test and evaluate the performance of SSU and compare it with other methods, we compared SSU and a conventional non-cooperative algorithm. We used the DEVS formalism, which provides us with an efficient way to explore related issues in mobile networks. The hierarchal nature of modeling in DEVS allows us to study different aspects of the target problem by providing precise information from different levels of the implemented model. Simulation results reveal the fact that, compared to the conventional method, SSU users benefit from more consistent services as their distance from the cell center increases. Also, these results show that for a given size of data file, cell edge users using SSU required less time to upload their data.

2. Background

LTE-A benefits from a number of technologies including Multiple Input Multiple Output (MIMO), Orthogonal Frequency Division Multiplexing (OFDM), wireless enhanced Inter-Cell Interference Coordination (eICIC), and Coordinated Multipoint (CoMP) [8]. These techniques help to provide high data rates for the users as well as meet the IMT-Advanced requirements. In addition, they are being used to overcome the transmission impairments such as Inter-Cell Interference (ICI). The latter is a major bottleneck for the cellular networks performance [9]. In particular, this problem affects cell edge users' performance. It also acts as a barrier for mobile network standards coming close to their theoretical rates [10]. In fact, ICI is a result of using the same radio resources in different cells in an uncoordinated manner [11]. To overcome these problems, different techniques including interference cancellation, interference coordination, and interference randomization have been investigated [2, 6, 12, 13, 14].

Among the various techniques that LTE-A has employed to improve user quality of experience, CoMP can be considered as a key technique to mitigate co-channel interference and increase per user capacity. CoMP refers to a set of BSs that are coordinated dynamically. CoMP BSs form coordination sets whose main objective is to mitigate interference and enhance the throughput from BSs to UEs, especially for the cell edge users [15]. As shown in Figure 1, three BSs establish a coordination set to provide better service for a user at the cell edge of the BSs. Compared to the users in the cell center, there are two main issues that cause problems for cell edge users. The first one is the lower signal strength due to the distance between the UE and BS, and the second one is higher interference level from the close proximity to the neighboring BSs. High data rates are relatively easy to maintain when one is close to the BS (like UE2 in Figure 1), but as distances between UE and BS increases, it becomes more difficult [6].

One approach to ensure high data rates regardless of the distance from the base station is to coordinate signals from multiple antennas and BSs. When a UE is on the cell edge, we can use the neighboring BSs signal in a coordinated way, and improve transmission quality. To do so, the BSs and UEs need to exchange information to create a CoMP set. This information includes scheduling, hybrid Automatic Repeat Request feedback, channel state information (CSI), and control information [5]. As seen in Fig. 1, BSs are connected through 3GPP interfaces (noted as X2), and they share the message received from their UEs with other BSs in the coordination set through these interfaces [5].

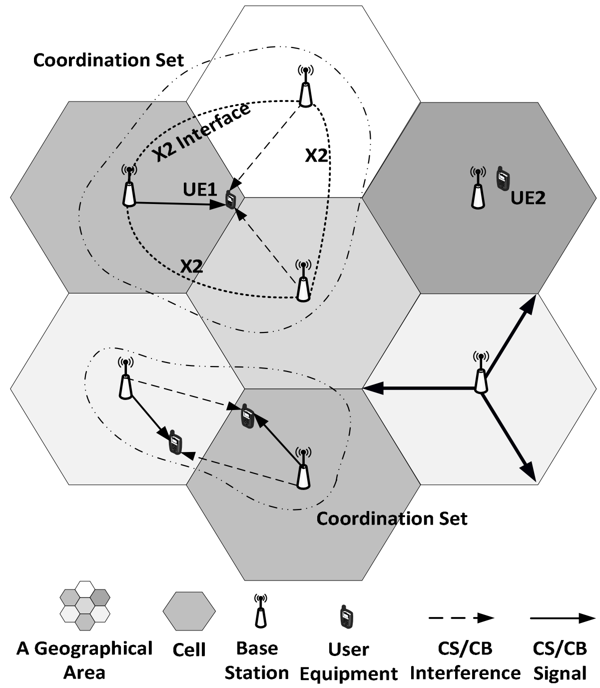

Figure 1. CS/CB transmission in LTE-Advanced

Based on the way that control information is shared among the transmission points, two CoMP implementations can be considered: centralized and distributed. In the former, a central unit holds all channel information and data from all UEs in the covered area. After scheduling, the unit sends the results to the coordinated BSs in the coordination set. This architecture has a high signaling overhead on the backhaul because all the BSs must send all of the UEs status information and data to the central unit. In addition, the central unit needs to send scheduling results for the BSs over the backhaul. Another challenge is the latency to support effective exchange of information between BSs in the coordination set. In distributed CoMP, the UEs share their channel status with their serving BSs and the serving BS of each UE forwards this information to the other BSs that could be in the coordination set. As such all the BSs in the coordination set act based on same schedule in a coordinated manner. The resulting distributed CoMP implementation has reduced infrastructure cost and less complexity. [3, 4, 6, 11, 16].

There are two schemas for CoMP in LTE-Advanced based on the way in which the data and scheduling information are made available at the BSs: Coordinated scheduling/Beamforming (CS/CB) and Joint Processing (JP). In the former, each UE is only served by its serving BS which is one of the BSs in the coordination set. The scheduling decisions are made to reduce interference among the BSs in the coordination set. In this method the exchange of scheduling information is required but UE data is not needed to be shared among the all BSs in the coordination set. In the Joint Processing scheme, the data to be transmitted to a single UE is transmitted from BSs in the coordination set simultaneously (Figure 2). This increases the signal quality at the UE and decreases interference. However in this method the amount of data exchanged over the backhaul can be very large [3, 5, 6, 8, 11, 17] and latency of data exchange between BSs can limit the achievable data rates.

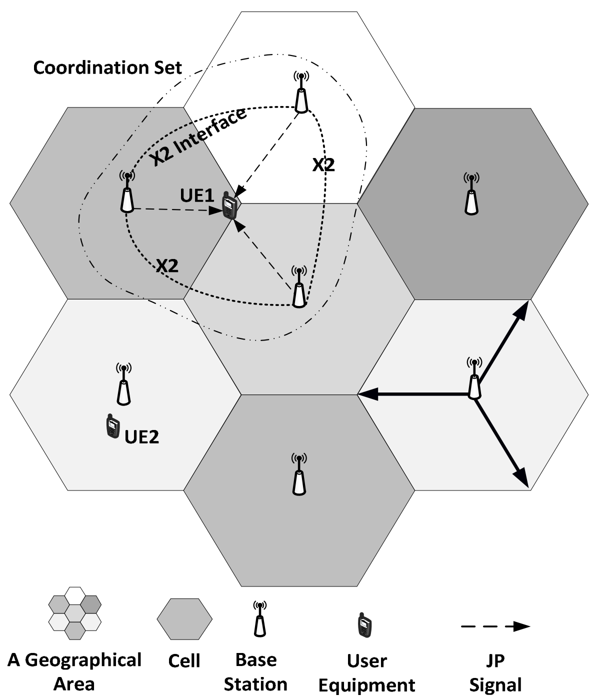

Figure 2. JP transmission in LTE-Advanced

There are numerous researchers working on Modeling and Simulation (M&S) of cellular networks, a useful method to test and evaluate new techniques. M&S can be used to study different aspects of a problem by changing test configurations. For instance in [18], the authors used M&S for testing in LTE networks. In [19], the authors focused on discontinuous reception in the LTE networks. This approach leads to better battery power usage of UEs (with potential increase in latency). They used OPNET as their platform for M&S. In [20], the authors investigated user equipment's quality of service (QoS) requirements in the LTE uplink and proposed a QoS-aware resource allocation paradigm for the LTE uplink scheduling. The authors used NS3 to evaluate and compare the performance of the proposed approach with two other time domain paradigms. In [21], the authors studied the handover procedure in LTE networks using NS2 as the simulation tool to investigate the effects of user data forwarding on the user connections. In [22], the authors presented an OPNET simulation model to investigate the uplink performance of LTE FDD and TDD modes regarding the latency and channel utilization. The LTE-A standard supports carrier aggregation by integrating contiguous or non-contiguous carriers at the base station. In [23], NS3 was used to implement a carrier aggregation module to study scalable video multicast to LTE-A user groups.

In our case, we used the DEVS formalism [24] to model the cellular network to test and evaluate SSU. DEVS is a formal framework for modeling generic dynamic systems [24]. The CD++ toolkit has been used as the framework for programming DEVS models [6].

3. SSU Algorithm

Uploading large files is a challenge in mobile networks communication. The limited bandwidth in a single connection between a UE and a BS slows down this process, particularly for cell edge users where the reception is weak. Our algorithm focuses on solving this issue by spreading the data transfer over a number of BSs that participate in a CoMP communication. The algorithm is based on the BitTorrent download algorithm over the web [7].

Initially, the UE creates a "*MetaInfo*" file that describes the large file to be transferred to its serving BS. This file is small in size, and it can be transferred quickly to the serving BS. Table 1 shows the *MetaInfo* format.

Key	Description
length	Length of file in bytes
name	Filename
piece size	Number of bytes in each piece
pieces	String consisting of the concatenation of all 20-byte SHA1 hash values, one per piece

Table 1. MetaInfo format

The piece size is usually a power of 2, and it is selected based on the file size. There is a tradeoff between the piece size and the efficiency of the upload algorithm. A large piece size would slow down the upload, as it will become similar to transferring a large file; on the other hand, a very small piece size will increase the overhead and will result in a very large MetaInfo file. The optimal piece size depends on different factors, such as the number of BSs involved in a CoMP uplink communication, as well as the number of handovers happening during the file transfer. Therefore, the piece size varies based on the conditions of the uplink, and can be tuned in different simulation scenarios to be investigated for each condition. The most common piece sizes in

BitTorrent data transfer technique are 256 KB, 512 KB, and 1 MB. Every piece is of equal length, except for the final piece, which is irregular. The number of pieces is determined by total length of the file divided by the piece size. Each piece is recognized by a SHA1 hash code generated from the data contained within that piece. These hashes are 20 bytes long and are lined up in the Metainfo file to form the pieces value dictionary.

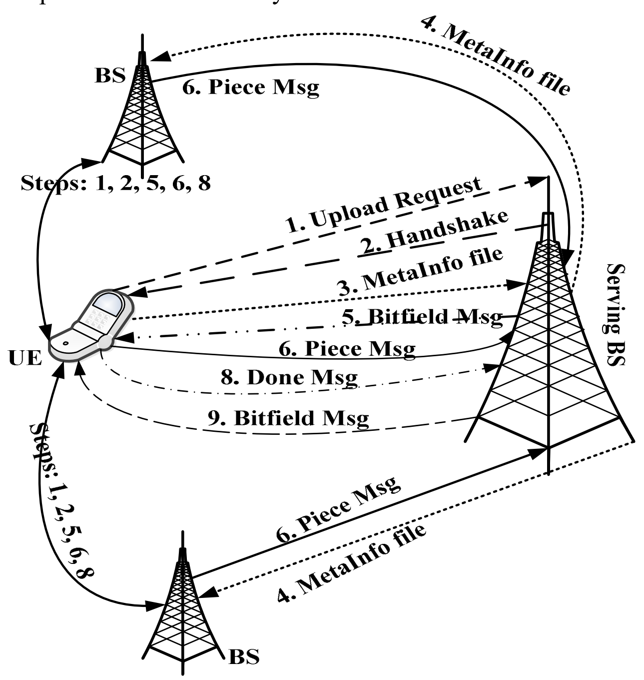

Figure 3. Segmented Upload Algorithm Message Transfer

Figure 3 shows the steps for uploading a large file from an UE to the serving BS. These steps are as follows:

i. The UE sends an *Upload Request* message to all the BSs in its CoMP set.

ii. The BSs reply by sending a *Handshake* message.

iii. The UE sends the *MetaInfo* file to the serving BS.

iv. The Serving BS forwards the *MetaInfo* file to other BSs in the CoMP set.

v. The BSs acknowledge the receipt of this file by sending the *Bitfield* message, which also tells the UE about the pieces available on the BSs.

vi. The UE starts sending the pieces by sending the *Piece* message to all the BSs in its CoMP set (because the messages are sent via TCP, they do not need to acknowledge the receipt of the messages as it is done in the TCP layer).

vii. The BSs send the received pieces to the serving BS through the *Piece* message, once they receive them.

viii. The UE stops the data transfer by sending the *Done* message, as soon as all the pieces are sent.

ix. The Serving BS acknowledges the receipts of all the pieces by sending a *Bitfield* message.

x. If the *Bitfield* message does not acknowledge the receipt of all the pieces, the UE continues sending the missing pieces until completion, and repeats from step *viii*.

As mentioned in step *vii*, the non-serving BSs in the UE's CoMP set forwards received pieces to the serving BS. The cost for such behaviour is overhead on the mobile network backhaul where BSs exchange data through the X2 interfaces. In the conventional non-cooperative method, each UE sends all of its pieces only to its serving BS and there is no concern about piece transfers from the non-serving BSs to the serving BSs. As a result, the SSU algorithm imposes more overhead on the network backhaul links.

4. Modeling of the Mobile Network in DEVS

We have defined the DEVS model for studying a mobile network employing the new algorithm. The model consists of various sub coupled models.

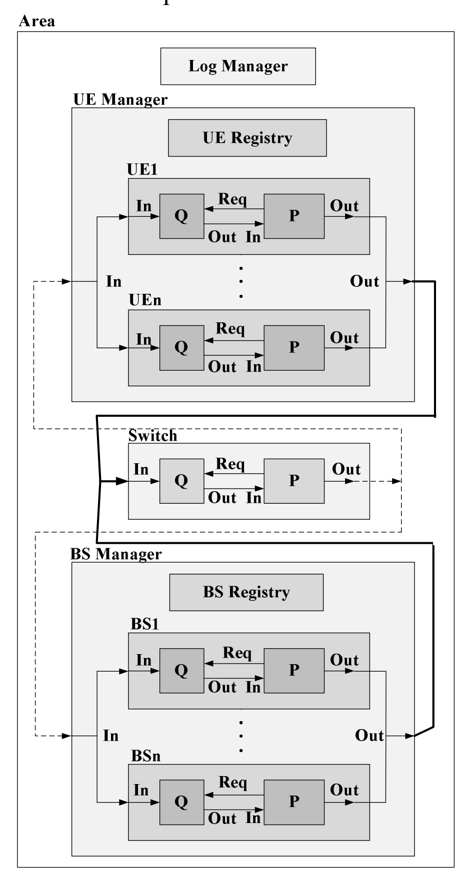

Figure 4. Simplified DEVS model hierarchy for mobile network model (Q: Queue, P: Processor)

As seen in Figure 4, the top level is called Area. This coupled model itself includes one atomic model, which is the Log manager and three other coupled models (Switch, UE manager and BS manager). The Log manger is responsible for gathering statistics during the simulations. The Switch model in Figure 4 models the communication between each pair of BSs and UEs. Instead of defining interconnections for each pair (which can grow quickly), the Switch is used to receive all the sent messages and broadcasts them to all the other models. The BSs and UEs can recognize their messages based on the destination address field of the received message. Both the BS manager and UE manager have same structure, but with different operations and each of them has a Registry unit, which is responsible for some control actions regarding BSs and UEs.

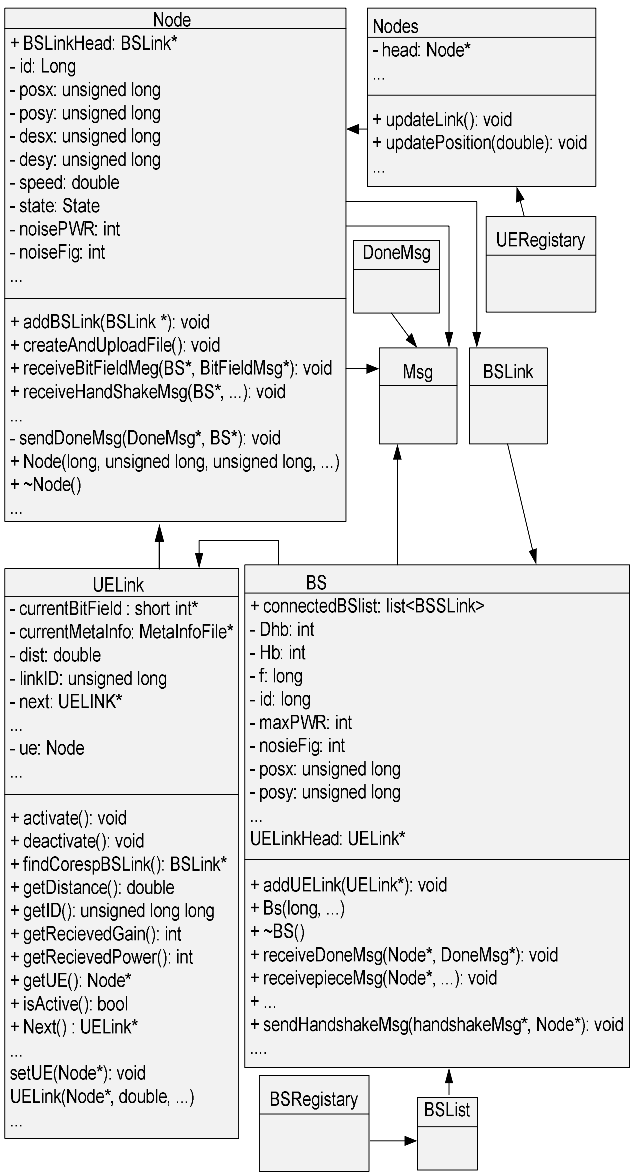

Figure 5. Simplified class diagram of the model

In addition, they can have an unlimited number of BS and UE models, depending on the Area size. The number of the UEs in UE manager is usually between four or five times the number of BSs. Both UE and BS models are coupled models, and they are composed of two atomic models: Queue and Processor. An arrival message at a Queue is processed based on the delay time. So among all the messages in the queue, the one with the least delay time leaves the queue first. The Processor of the UEs and the BSs operates based on the definition of SSU.

Aside from the atomic model components described earlier, other passive classes have been added to complete the model. Figure 5 shows a simplified UML class diagram showing these classes. The BS class represents a BSProcessor by using id, type, coordinates, height from ground, height from the average rooftop, carrier frequency, transmission power, antenna gain, and a list of connections with the UEs in range. The Node class characterizes a UEProcessor with an id, current coordinates, destination coordinates, speed, transmission power, antenna gain, and a list of connections to the in-range BSs. The UELink class is a linked list held by every BS and contains uplink parameters of each UE in range. These parameters include the separation distance, path loss, and the received power. Similarly, the BSLink class is a linked list held by every Node object and contains the parameters similar to those in the UELink class, but for the downlink connection. The two respective classes have methods to calculate link parameters such as propagation model, path loss, and the received power in rural area settings.

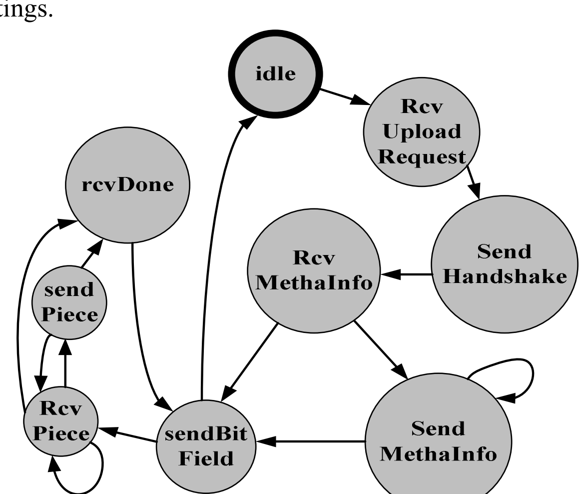

Figure 6. UELink state diagram

In this model, a UEProcessor only handles the upload of one file at a time, and therefore, its state transitions directly correspond to the different steps of the proposed algorithm. The UEProcessor states are: *Idle*, *CreateAndUpload*, *UploadReqest*, *RcvHandshakeWait*, *RcvHandshake*, *SendMetaInfo*, *RcvBitFieldWait*, *RcvBitField*, *SendPiece*, *SendDone*, *RcvDoneBitFieldWait*, and *RcvDoneBitField*. Since a BSProcessor handles incoming and outgoing messages to neighboring BSs and multiple UEs, its state machine tends to be complex. To simplify its state transitions, a BSProcessor only cycles through four states, namely, Idle, Receive, Process, and Send, once for each external message received. Thus, the behavior of the model depends on the state of the link between the BS and the corresponding node at which the received message originated. Figure 6 shows the UELink state diagram.

We have also implemented a conventional non-cooperative algorithm in order to compare it with SSU. This non-cooperative algorithm represents a simplistic upload model where a UE only communicates with its serving BS. The upload starts with an upload request message from the UE (similar to SSU), and it is acknowledged by the BS with a handshake message. A file is then uploaded in a stream of variable sized packets, or segments. The size of the packets depends on the bandwidth of the link. The last packet is followed by a Done message to notify the BS that the file upload is complete.

5. Simulation scenario and results

To assess the potential of SSU, we run a series of system level simulations. Since the algorithm aims to improve the throughput and data rates for cell edge users, the effectiveness of the algorithm needs be evaluated as a function of distance from the cell center. In each iteration of the simulation, the UEs are randomly positioned in the system area within a narrow predefined range of distances, measured from the center of the serving BS cell. The simulations were carried out in a rural area setting, with an operating carrier frequency of 900 MHz, and a transmission bandwidth of 5 MHz. The noise variance is assumed to be fixed at -174 dBm/Hz and the log-normally distributed shadowing (LogF) is set to a standard deviation of 10dB. The other detailed simulation parameters are listed in Table 2 [25].

The UERegistry atomic model is responsible for periodically updating the UEs' locations based on their current locations, their predefined random destinations and speeds. This periodically updates the propagation model (L) for the links between each pair of BSs and UEs. We need the updated propagation model to calculate received signal power at the receiver side. Then, we can calculate the available data rate at the link between UEs and BSs. The following formulas show the required steps to calculate link data rate.

Let's assume that R is the BS-UE separation in kilometers, f is the carrier frequency in MHz, Dhb is the base station antenna height in metres, measured from the average rooftop level and Hb is the BS antenna height above ground (in meters). Then the Macro cell propagation model for rural area is given by the following formula [25].

$$L_{rural} = 69.55 + (26.16 * log_{10} f) - (13.82 * log_{10} hb) + \left((44.9 - (6.55 * log_{10} hb)) * log_{10} R\right) - (4.78 * (log_{10} f)^2) + (18.33 * log_{10} f) - 40.94$$

Considering the log-normally distributed shadowing (LogF) with standard deviation of 10dB, the pathloss is given by [25]:

$$pathloss = L_{rural} + LogF$$

The received signal power at each UE and BS is calculated by [25]:

$$RX\_PWR = TX\_PWR - Max(pathloss - G\_TX - G\_RX , MCL)$$

where RX_PWR is the received signal power, TX_PWR is the transmitted signal power, G_TX is the transmitter antenna gain, G_RX is the receiver antenna gain and MCL is the minimum coupling loss.

The link data rate can then be calculated taking into account Additive White Gaussian Noise (AWGN), using the following equation, where B is the transmission bandwidth and N_0 is the noise variance.

$$data\ rate = B \log_2(1 + \frac{RX\_PWR}{N_0 \times B})$$

Value	Parameter
900 MHz	Frequency
5 MHz	Transmission bandwidth
-174 dBm/Hz	Noise Density
80 dB	MCL
15 dB	BS Antenna Gain
15 meters	BS Antenna Height above rooftop (Dhb)
45 meters	BS Antenna Height above ground (Hb)
10dB	LogF
0.5MB - 64MB	File size
43 dBm	Maximum BS power
30 dBm	Maximum power per DL traffic channel
15 dBm	Minimum BS power per user
5 dB	BS Noise figure
21 dBm	Maximum UE power
-50 dBm	Minimum UE power
9 dB	UE Noise figure

Table 2. Key simulation parameters

A set of simulations was performed in a rural area setting with an operating area of 8 km by 8 km, and BS-UE distances increasing in increments of 800 meters up to 8 kilometers. In other words, the first simulation positioned UEs within the first 800 meters around their serving BS, the second simulation had UEs placed between 800 and 1600 meters from the BS, and so on. The simulations were allowed to run until all the file uploads were complete and the simulation statistics were collected. These files were then analyzed and some of the chosen results are shown in the figures below.

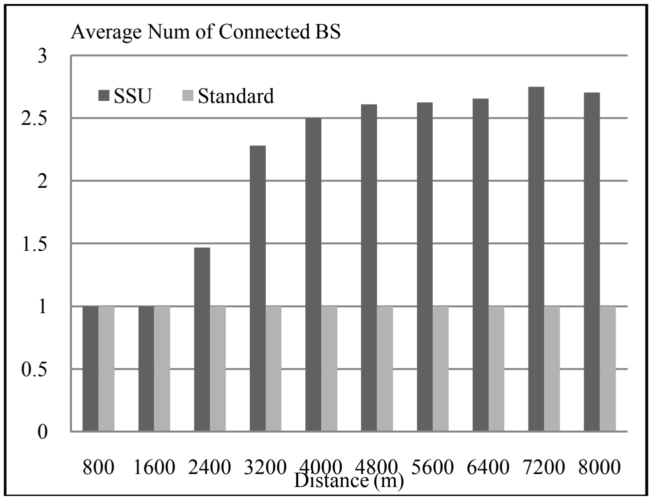

Figure 7. Number of connected BSs vs. Distance from BS

A user can communicate with its serving BS when traveling in a cellular network that uses a conventional non-cooperative algorithm. This case is true even when the user is in the cell edge areas. On the other hand the SSU algorithm provides higher data rate allowing the UEs to communicate with the BSs in the coordination set while they are close to the cell edge area. Figure 7 shows the average number of BSs that each UE communicates with during the uploading process. As the distance between UEs and the cell center increases it is more likely that the UEs receive other BSs signal. Figures 8 and 9 show that SSU algorithm uses this fact effectively improves UEs performance.

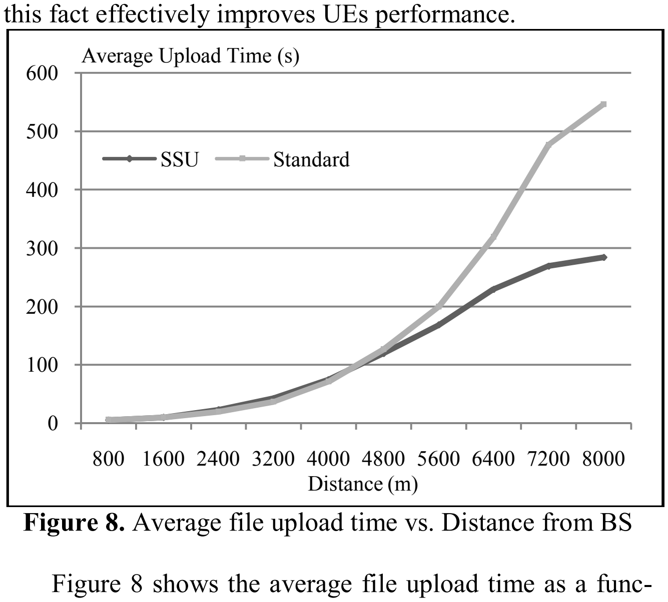

Figure 8. Average file upload time vs. Distance from BS

Figure 8 shows the average file upload time as a function of distance for the SSU algorithm, as well as the conventional non-cooperative algorithm. The upload time is measured from the moment that the upload process is initiated until the last message is sent. For the shared segmented upload algorithm, it starts with the UploadRequest message from the UE, and it ends with the BitField message from the UE's serving BS. As it can be seen, SSU starts to impact the upload time when the UEs are about 4400 meters away from the serving BS. Closer to the BS, it adds a small overhead caused by the additional control messages.

Similarly, Figure 9 compares the average data rate and the distance between the UEs and their serving BSs. Again, the shared segmented upload algorithm starts to improve the uplink data rates around 4400 meters with slight negative effects closer to the BS. The SSU algorithm is very effective at improving the uplink data rates close to the cell edge. From the results shown, at the cell edge, the SSU algorithm nearly doubles the data rate and halves the upload time, compared to conventional non-cooperative schemes.

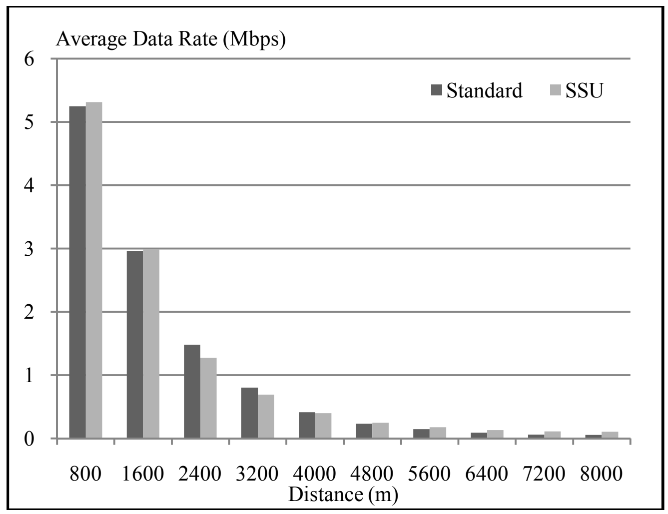

Figure 9. Average data rate vs. Distance from BS

6. Conclusion

We introduced the Shared Segmented Upload (SSU) algorithm as an uplink schema for LTE-Advance networks. This method improves the cell edge user's uplink performance by transferring large files in small segments from a single UE to the BSs in a coordination set. The Discrete Event System Specification (DEVS) formalism and CD++ software were used to model and implement the cellular network, the SSU algorithm, and a conventional non-cooperative algorithm. Simulation results reveal that the SSU algorithm provides better services for the users as their distance increases from cell center. Compared to the conventional method, SSU provides higher data rate for the users and reduces the required time for a UE to upload its data to the network. Considering the huge amount of data that required to be transmitted over a mobile network, further investigation is required to study its influence on the backhaul. Moreover, we need to extend the proposed SSU algorithm to reduce such overhead.

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