Traffic Monitoring in a LTE Distributed Antenna System

Seyed Amin Hejazi[1], Shawn P. Stapleton[2]
[1]Simon Fraser University, Burnaby, BC, Canada
[2]Dali Wireless Inc., Burnaby, BC, Canada

***Abstract*—An Intelligent Distributed Antenna System (IDAS) fed by a multiple Base Transceiver Station (BTS) has the ability to distribute the radio resources over a given geographic area. To enable an efficient distribution of radio resources amongst the antenna modules, a server is utilized to dynamically allocate the remote antenna modules to the BTSs using a Self-Optimized Network (SON) algorithm. Monitoring the traffic on the DAS network is required in order to plan, configure and optimize the SON. This paper investigates a practical method to monitor the required SON information in order to properly configure the remote antenna allocation. An LTE SON system is demonstrated using the suggested method for traffic monitoring.**

***Index Terms*—Distributed Antenna System, Traffic Monitoring, LTE and LTE-Advanced.**

I. Introduction

A non-uniform distribution of users, in a high demand network, can present an inefficient utilization of system resources. This inevitable results in a high call blocking rate. The network performance will be sub-optimum as traffic environments change. It is therefore necessary to dynamically self-optimize the network according to the traffic environment, especially when cell traffic loads are not uniformly distributed amongst the antenna modules. This is one of the important optimization issues in Self-Optimizing Networks (SON) for 3GPP LTE [1]. In order to balance an imbalanced network, a SON enabled network can offload the high load eNodeBs (LTE base station) to low load eNBs (eNodeB) by adjusting the network control parameters. Use of tilted antennas [2], dynamic sectorization [3], and dynamic cell-size control (cell breathing) [4], have been suggested for load balancing. Dynamic load redistribution is provided by these techniques in real-time according to the current geographic traffic conditions. Intelligent Distributed Antenna System (IDAS) is considered as a real-time approach to control the radio coverage patterns [5].

Distributed Antenna System (DAS) was originally introduced to solve dead spot coverage problems [6]. In DAS, multiple distributed low-power antenna modules connected to a central unit where radio signals are transported to and from the central unit in either analog or digital form. Note that the central unit performs all eNBs' baseband processing. The power consumption of a cellular network is reduced by replacing a single high-power antenna module with several low-power antenna modules distributed over the same coverage area as the single antenna. In DAS, antenna modules are separated by a large distance, both microscopic and macroscopic diversities can be exploited where as conventional centralized antenna systems exploit only microscopic diversity [7]. The applications of DAS in cellular networks have been widely investigated [8], [9].

In a traditional DAS system, only the discrete resources of a specific eNB fed to a set of antennas associated with that eNB can be utilized, although all resources are accumulated into an eNB hotel. Since the eNBs are collocated in an eNB hotel, according to an SON algorithm, the aggregated resources of the discrete eNBs as a single pooled resource can be allocated to set of antenna modules. Provisioning assumptions are typically predicated on worst-case traffic assets in all areas, network design is wasteful a large percent of the time, inevitably resulting in over- or under-provisioning of the fixed resources. Traffic resources either go unused or are under-provisioned and are insufficient to handle the offered traffic. Both circumstances give rise to the same outcome: lost revenue and lost opportunity. When a site's traffic resources are idle and unused, the traffic asset fails to provide an optimal return on investment. But a site that lacks sufficient capacity to support the offered traffic at any point during the day garners dropped calls, lost revenues, and dissatisfied customers.

This paper investigates a practical method to monitor the required information for SON to properly configure the remote antennas allocation. An LTE system example is demonstrated using the suggested method for traffic monitoring.

II. System Model and Problem

A DAS architecture of a 3GPP LTE multiple eNodeB (eNB) system is shown in Fig. 1. DRUs (Digital Remote antenna module Units) are connected to an eNB hotel (BTS Hotel) via optical fiber and one or more Digital Access Units

S. A. Hejazi is with the School of Engineering Science, Simon Fraser University, Burnaby, Canada, V5A 1S6. Email: shejazi@sfu.ca.
S. P. Stapleton is with the Dali Wireless (Canada) Inc., Burnaby, Canada, V5A 4N6. Email: sstapleton@daliwireless.com.

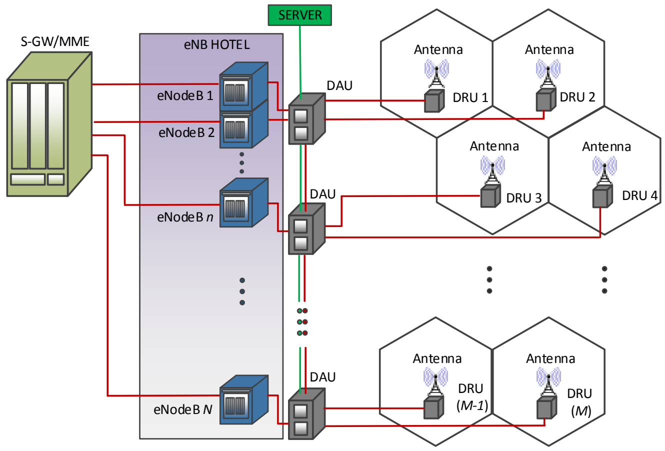

Fig. 1. Structure of IDAS network.

(DAU). The DAUs are interconnected with multiple eNBs. This capability enables the virtualization of the eNB resources at the independent DRUs. The eNB hotel is linked to a Service Gate-Way (S-GW) or a Mobile Management Entity (MME). DRUs are allocated such that each DRU allocated to a given eNB is simulcast. For the simulcasting operation, the access network between the eNB hotel and DRUs should have a multi-drop bus topology. In Intelligent DAS (IDAS), the DAUs dynamically assign the radio resources of the various eNBs to the independent DRUs according to the traffic demand. The traffic monitored at the DAU from different DRUs will help the server to dynamically allocate the traffic resources to the required geographical areas. The server dynamically changes the configuration of the DRU allocation to various eNBs.

Load balancing across a network is a challenging problem in LTE systems. IDAS can solve this problem using a SON algorithm with Traffic monitoring capabilities. A SON algorithm usually optimizes the objective function to define a new DRU allocation configuration, i.e. maximize the system capacity, maximize the number of satisfied user, and minimize the number of blocked calls.

A method is required for monitoring the information to drive a SON algorithm such as the channel quality between each individual pair of DRUs and UEs (User Equipments), the number of UEs associated with a given DRU and which UE is associated with which DRU. Monitoring this information helps the SON algorithm obtain a better DRU allocation configuration. Note that, UE_i associated with DRU_j when it is closer to DRU_j than the other DRUs.

III. Solution

The uplink receive power at each DRU is primarily influenced by the distance between the UE and the DRU. Therefore, UE_i is associated with DRU_j when the received power of UE_i at DRU_j is greater than the UE_i received power at the other DRUs. One solution to determine that UE_i is associated with a given DRU is by comparing the received uplink powers of UE_i at the different DRUs.

Although demodulating the Physical Uplink Control Channel (PUCCH) will extract the uplink control information such as the Channel Quality Indicator (CQI) [10, Ch. 16.3], this technique will require complex hardware resources. On the other hand, the CQIs transmitted by UEs represent the quality of the channel between the eNB and UE, which is not sufficient for the SON algorithm to design a new DRU allocation configuration. The SON algorithm needs the channel quality between the DRU and UE, not between eNB and UE, to properly optimize the DRU allocation configuration. Therefore, extracting the physical reference signals from the received uplink signal at the DRU, for each individual UE, is one solution to estimate the channel quality between DRU_j and UE_i.

The Demodulation Reference Signals (DM-RSs) associated with the physical uplink channel are primarily provided for channel estimation and therefore present in every transmitted uplink slot [11, Ch. 10.2.2]. A DM-RS is intended for a specific UE and is only transmitted in the RBs (Resource Block (group of subcarriers)) assigned for transmission to that UE. The DM-RS are based on Zadoff-chu sequences with constant amplitude.

"Extracting Downlink Control Information" and "Extracting Uplink Radio Frame" are two required procedures which are explained in the following subsections,

A. *Extracting Downlink Control Information (EDCI)*

The Downlink Control Information (DCI) which includes downlink scheduling assignments, uplink scheduling grants, power-control commands and other control information for UEs [11, CH. 10.4.3], will be obtained from the received downlink signal at each DAU via the eNB by using the following steps (Fig. 2).

Step 1- Synchronization and cell search: The detection of two Primary Synchronization signal (PSS) and Secondary Synchronization Signal (SSS) not only enables time and frequency synchronization, but also provides the identity of cell and cyclic prefix (CP) length, as well as whether the cell uses Frequency Division Duplex (FDD) or Time Division Duplex (TDD) [10, Ch. 7.2]. The PSS and SSS are each comprised of a 62 length Zadoff-chu sequence [10, Ch 7.2.1] symbols, mapped to the central 62 subcarriers around the D.C. subcarrier, which is left unused [11, Ch. 14.1.2]. This structure enables the detection of the PSS and SSS using a size-72 Fast Fourier Transform (72-FFT) (Fig. 2, EDCI (1)).

Step 2- Physical Broadcast Channel (PBCH) decoding: The Master Information Block (MIB) transmitted using PBCH consists of a limited amount of system information such as cell bandwidth and Physical Control Format Indicator Channel (PCFICH) configuration of the cell. Detectability without knowing the system bandwidth is achieved by mapping the PBCH only to the central 72 subcarrier (minimum possible LTE bandwidth of 6 RBs), regardless of the actual system bandwidth. This structure enables decoding of the PBCH using 72-point FFT [10, Ch. 9.2.1] (Fig.2, EDCI (2)).

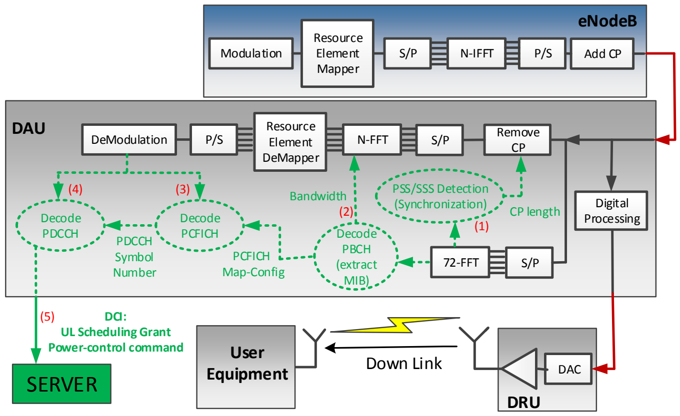

Fig. 2. EDCI: UL control information extracting procedure from DL signal

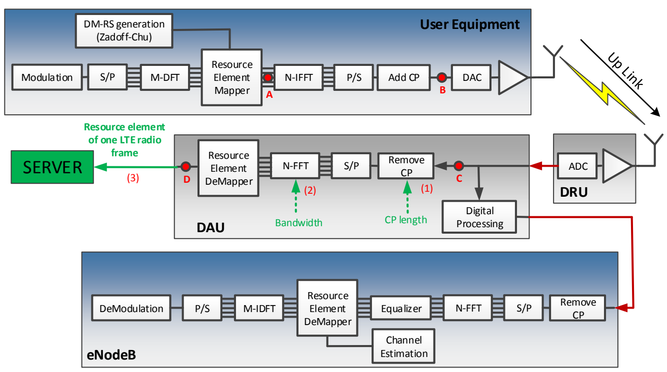

Fig. 3. EURF: De-mapping the resource element of one radio frame from UL signal

Step 3- Physical Control Format Indicator Channel (PCFICH) decoding: The PCFICH carries a Control Format Indicator (CFI) which indicates the size of control region in terms of the number of OFDM symbols (i.e. 1, 2 or 3) [10, Ch. 9.3.3]. Figuring out the value of the CFI is possible by decoding the PCFICH (PCFICH Map configuration is obtained at step 2). Note that CP length obtained at step 1 helps to remove the CP from the received digital symbol and the actual bandwidth obtained at step 2 helps to determine the FFT size (Fig. 2, EDCI (3)).

Step 4- Physical Downlink Control Channel (PDCCH) decoding: The PDCCH carries the DCIs. DAU need to blindly detect all UEs' PDCCH by searching the PDCCH region. PDCCH region is detected by decoding the CFI in step 3. Note that, the blind decoding is performed for all possible UEs to collect the control information for all users, separately [11, CH. 10.4.3] (Fig. 2, EDCI (4)).

Step 5- Transmitting to Server: transmit all control information for all users to the server via an optical fiber (Fig. 2, EDCI (5)).

B. Extracting Uplink Radio Frame (EURF)

The LTE UL radio frame can be extracted with the following steps (Fig. 3),

Step 1- Removing CP and Performing the N-FFT: CP length and actual bandwidth were obtained in step 1 and 2 of "Extracting Downlink Control Information", respectively

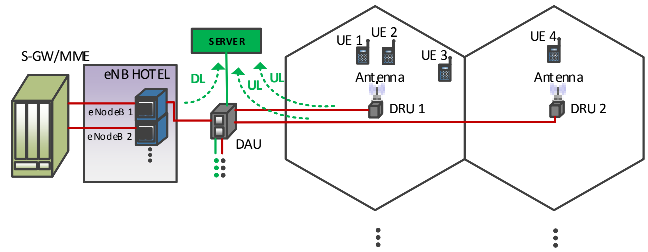

Fig. 4. Structure of Traffic Monitoring.

(Fig. 3, EURF (1)).

Step 2- Build LTE radio Frame: LTE Frame Builder saves all the OFDM symbols after the N-FFT and builds a LTE radio frame (10 ms) (Fig. 3, EURF (2)).

Step 3- Transmitting to Server: separately transmit all DRUs LTE radio frame to server (Fig. 3, EURF (3)).

Now, by knowing the uplink scheduling map obtained from EDCI and uplink LTE radio frame of each DRU obtained from EURF, the server can easily compare received power strength of different UEs based on scheduling map and make a decision whether which UE is associated to which DRU.

Since the DM-RSs are always transmitted with the same power as the corresponding physical channel, estimation channel quality between each pair of DRU and UE can be done using DM-RS symbols obtained from EURF and power control command obtained from EDCI.

It is worth to mention that, the uplink power control insures that the received power of different UEs should be almost the same at the eNB. Since the uplink signals from all the UEs at the DRUs are summed before the eNB, the ratio of the number of UEs belonging to a different DRU is the same as the ratio of uplink power strength at point *C* in Fig. 3 for the different DRUs (equation (1)). Note that, there is no need to extract downlink control information and uplink radio frame to find this ratio.

$$\frac{N_i}{N_j} = \frac{P_i}{P_j} \qquad (1)$$

where N_i and P_i are the number of UEs associated with DRU_i and the uplink power strength at DRU_i during at least one radio frame. Note that the number of users cannot be obtained by measuring only the received power at the DRUs.

In the following section we demonstrate an example to show how the solution method helps to monitor the traffic.

IV. Example of Traffic Monitoring

Fig. 4 demonstrates an example when 4 users are distributed and supported by 1 eNB and 2 DRUs.

Cell bandwidth is obtained after synchronization and decoding the PBCH (EDCI, step 1 and 2). In this example, 1.4 MHz (6 RB) bandwidth is used for transmission where 2 edge RBs are assigned to users as Physical Uplink Control Channel (PUCCH) and 4 center RBs are assigned to users as Physical Uplink Share Channel (PUSCH) at each sub-frame. The

	SF1		SF2		SF3		SF4		SF5		SF6		SF7		SF8		SF9		SF10	
	TS1	TS2	TS1	TS2	TS1	TS2	TS1	TS2	TS1	TS2	TS1	TS2	TS1	TS2	TS1	TS2	TS1	TS2	TS1	TS2
RB1(PUCCH)																				
RB2(PUSCH)	UE3		UE2		UE3		UE4		UE1		UE4		UE3		UE2		UE1		UE1	
RB3(PUSCH)	UE2		UE1		UE1		UE4		UE3		UE2		UE4		UE3		UE2		UE4	
RB4(PUSCH)	UE1		UE4		UE4		UE2		UE3		No UE		UE4		UE4		UE3		UE2	
RB5(PUSCH)	UE1		UE4		UE4		UE3		UE2		UE1		UE1		UE4		UE3		UE2	
RB6(PUCCH)																				

Fig. 5. UL scheduling map for one LTE radio frame (SF: sub-frame, TS: time slot)

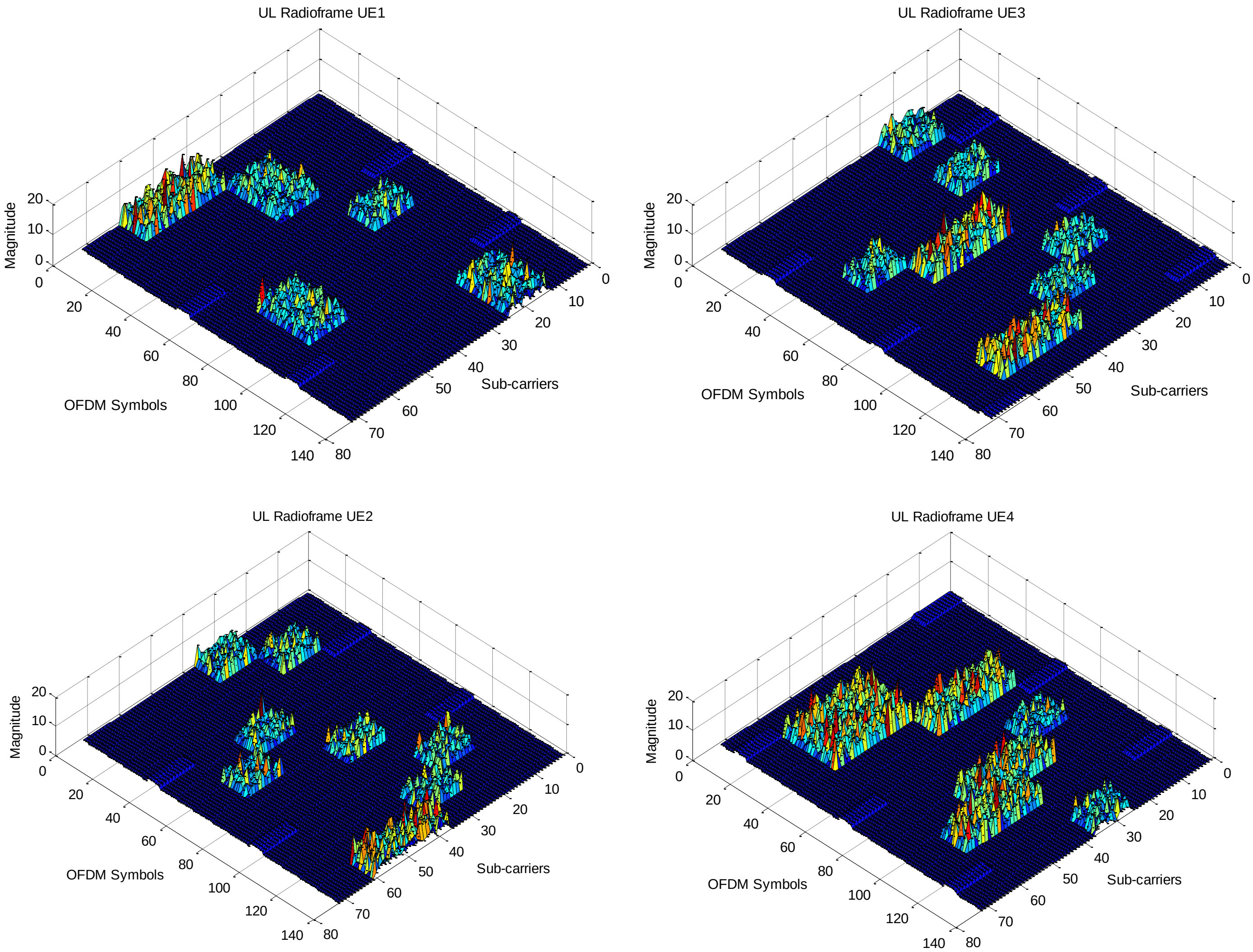

Fig. 6. Mapped resource elements of four UE1, UE2, UE3 and UE4 during one LTE radio frame.

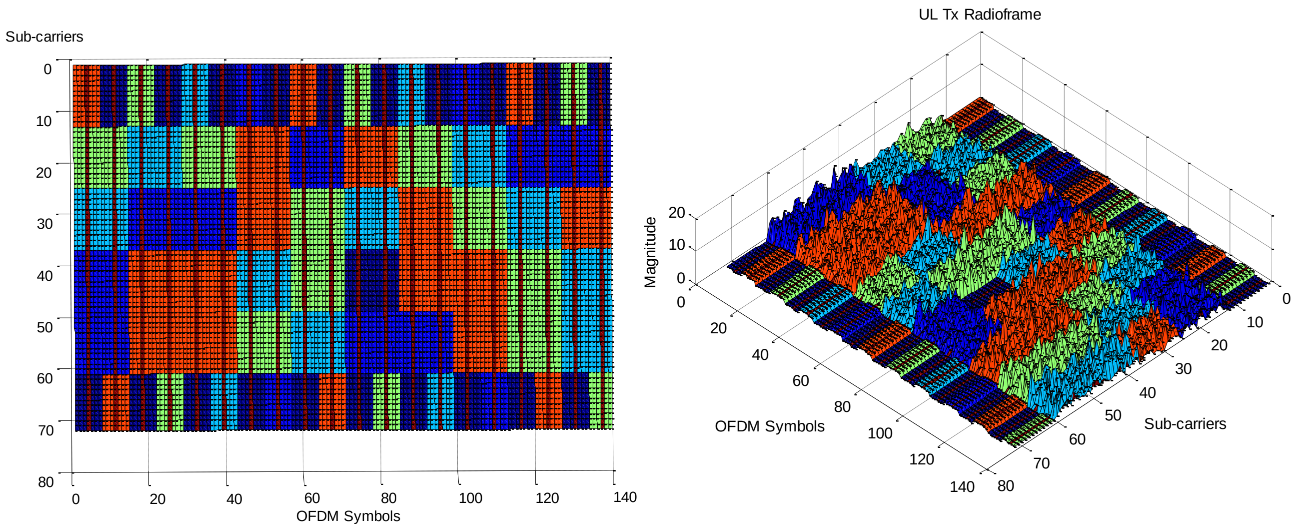

Fig. 7. Mapped resource elements of four UE1, UE2, UE3 and UE4 together.

uplink scheduling map for one radio frame is shown in Fig. 5 which is obtained from decoding the PDCCH.

Before building the radio frame from received signal at each DRU, let's follow how the LTE frame looks like at each individual UE. Fig. 6 shows the magnitude of mapped resource element during one radio frame for different users at point *A* of Fig. 3. Note that, the mapping resource elements are based on decoded UL scheduling grant from PDCCH at each user (EDCI, step 5).

All mapped resource elements for the different users are concatenated in Fig.7 to verify the scheduling map decode in Fig. 5. Note that the 4th and 11th OFDM symbols (red line) of each sub-frame are reserved for DM-RS which is generated by Zedoff-chu sequence with constant amplitude.

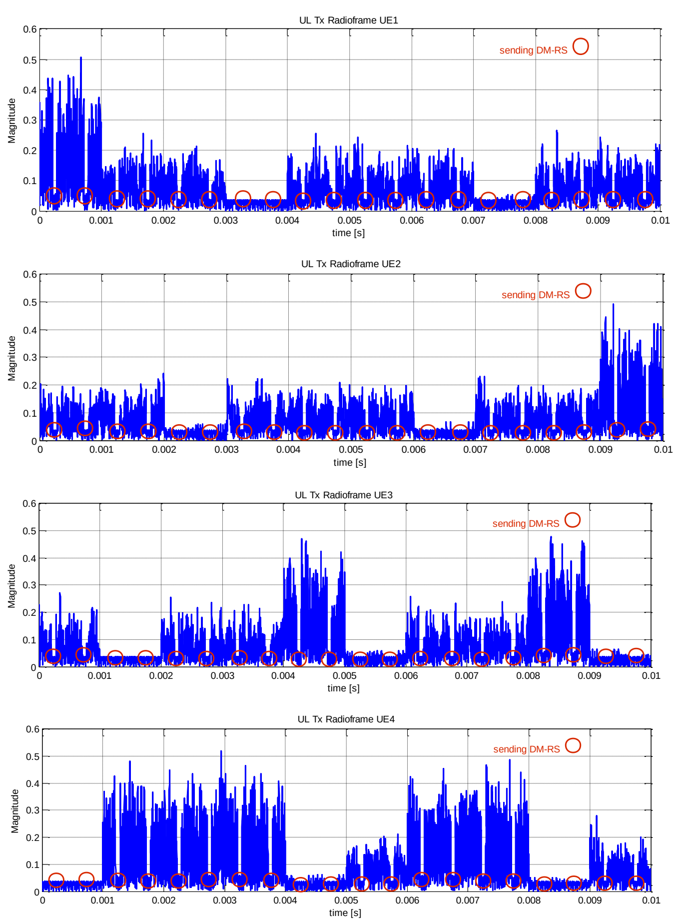

Fig. 8. The signals of point B in Fig. 3 for UE1, UE2, UE3 and UE4 during one radio frame.

Fig. 8 shows signals at point *B* in Fig. 3 after performing a 72-point FFT (when 1.4 MHz is the bandwidth), making them serial and adding CP for different users during one LTE radio frame (10 ms). The DM-RS signals with constant amplitude are shown as well.

The received combination of uplink signals is converted to digital baseband in the DRU using an ADC (Analogue to Digital Convertor) and they are transmitted to the DAU by an optical fiber.

Fig. 9 shows the combination of all received users digital signals at point *C* in Fig. 3 at two different DRUs. The number of UEs associated with DRU1 is approximately three times greater than DRU2 based on what is explained in section III, equation (1). This is because; the received power strength over one radio frame (1 ms) at DRU1 is approximately three times greater than DRU2.

The magnitude of the de-mapped resource elements of the received signal at point *D* in Fig. 3, for one radio frame, are shown in Fig. 10 and Fig. 11 for DRU1 and DRU2, respectively. Note that the de-mapped resource elements are obtained after removing CP and performing a 72-point FFT on the received signal at each DRU (EURF, step 5). The left figures of Fig. 10 and 11 show color figures in such a way that colors identify different power level i.e. red and green are assigned to highest and lowest power level, respectively. The right figures of Fig. 10 and 11 distinguish each users' RBs with different color, e.g.

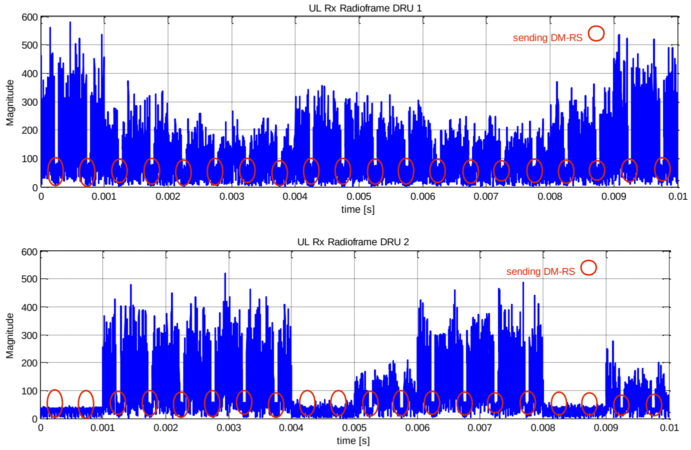

Fig. 9. The received signals at point C in Fig. 3 at DRU1 and DRU2 during one radio frame.

dark blue, light blue, green and red are assigned to user 1, 2, 3 and 4, respectively.

Now, by knowing the uplink scheduling map obtained from EDCI step 5, the server can easily compare received power strength of UE_i (i = 1, 2, 3 or 4) at the RBs associated to UE_i at DRU1 and DRU2 and make a decision whether UEi is associated with DRU1 or DRU2. We define, UE_i associated to DRU_j when the received power of UE_i at DRU_j is greater than the UE_i received power at the other DRUs, i.e. in this example, UE_1, UE_2 and UE_3 is associated with DRU1 and UE_4 is associated with DRU2. In other words, UE_i is associated with DRU_j when it is closer to DRU_j than the other DRUs.

Since the DM-RS symbols are always transmitted with the same power as the corresponding physical channel, received power strength comparison can be done by de-mapping only DM-RS symbol by performing the 72-point FFT only at the 4^{th} and 11^{th} symbol of each sub-frame. Although, de-mapping only the DM-RS decreases the required memory size at the DAU than de-mapping all the symbols, it requires a complex DM-RS detector with an accurate synchronization tool to extract DM-RS signal.

Fig. 12 shows the magnitude of the de-mapped DM-RS resource elements of the received signal at DRU1 and DRU2. Different colors in the Figures demonstrate the power levels. Not that, since the DM-RS symbols were generated based on Zadoff-chu sequences with constant amplitude, all DM-RS of specific UE_i have equal constant amplitude.

The server can estimate the channel quality between DRU_j and UE_i using the de-mapped DM-RS frames (EURF step 3) transmitted from DAU to server and UL control information (EDCI step 5) transmitted from eNB to server such as power control command and UL scheduling grants.

I. Conclusion

A LTE traffic monitoring method is required for a SON algorithm to properly configure a remote antenna allocation in a DAS based network. The method utilized extracts the downlink and uplink signals in the central unit. Channel estimation between each individual pair of DRU and UE, number of UEs associated with a DRU and which UE is associated to which DRU, are all required information for SON. This paper proposed a practical method to monitor these information.

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Seyed Amin Hejazi was born in Iran. He received the B.Sc. in Electrical Engineering from University of Tehran, Tehran, Iran, in 2007, and the M.Sc. degree in Electrical Engineering from Amirkabir University of Technology, Tehran, Iran, in 2009. Since September 2009, he has been with the Department of Engineering Science, Simon Fraser University, working towards the Ph.D. degree. His research interests include LTE, Distributed Antenna System, Load-Balancing, and Self-Optimizing Network.

Shawn P. Stapleton was born in North Bay, Ont., Canada. He received the M.Eng. degree in microwave engineering in 1984 and the Ph.D. degree in engineering in 1988, both from Carleton University, Ottawa, Canada. He is the CTO of Dali Wireless Inc. and is currently a Professor on sabbatical from Simon Fraser University in Electrical Engineering. Dr. Stapleton is a Fellow of the Advanced Systems Institute. His research at SFU has focused on integrated RF/DSP applications for Wireless Communications. While at Simon Fraser University he developed a number of Adaptive Power Amplifier Linearization techniques ranging from Feedforward, Delta-Sigma Modulators, and Work Function Predistortion to Digital Baseband Predistorters. He has published over 100 technical papers on Linearization and Power Amplification and has given many international presentations on the subject.

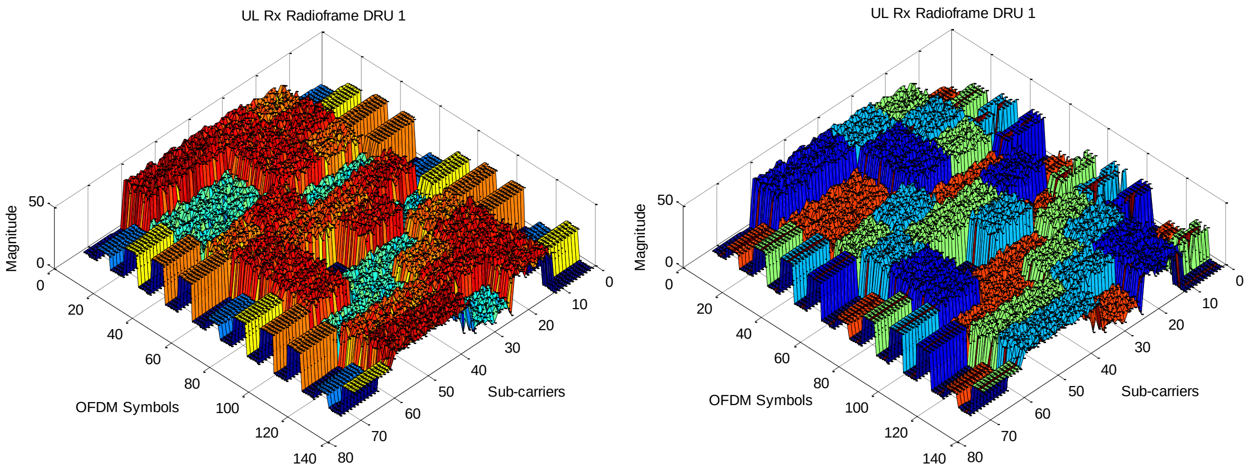

Fig. 10. The magnitude of de-mapped resource elements of received signal at point D in Fig. 3 for DRU1.

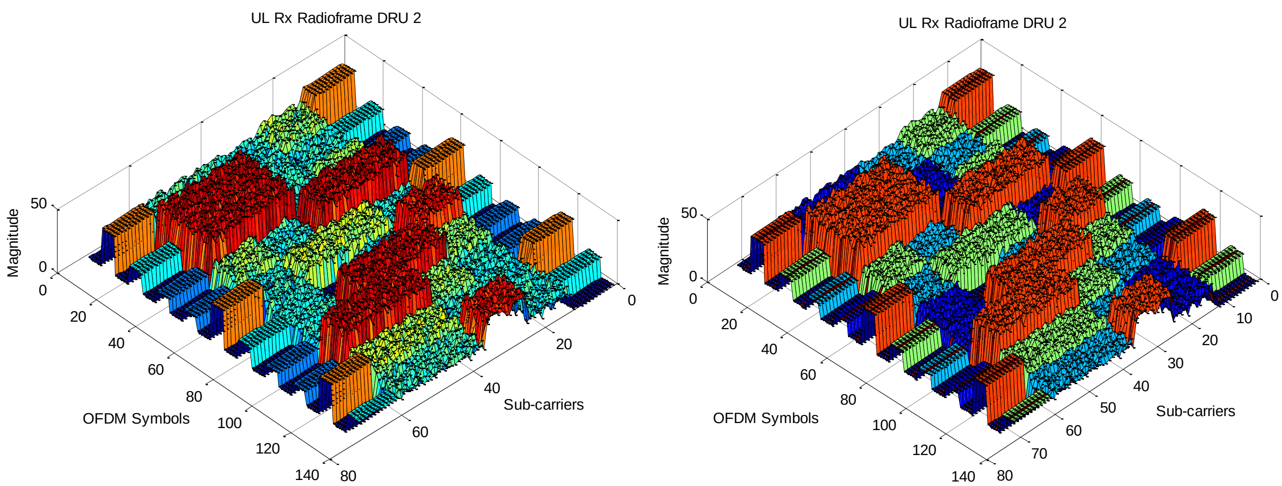

Fig. 11. The magnitude of de-mapped resource elements of received signal at point D of Fig. 3 for DRU2.

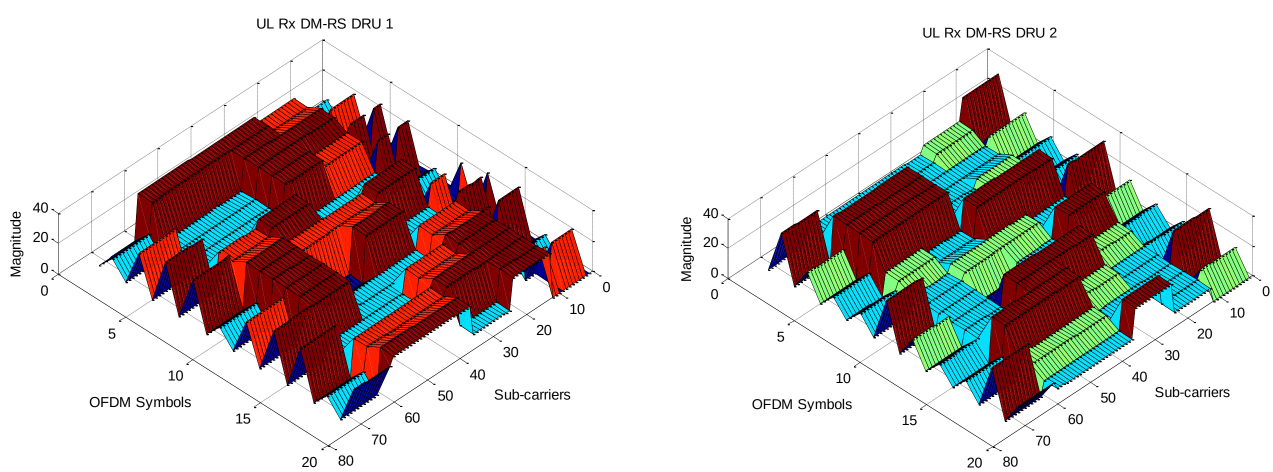

Fig. 12. The magnitude of de-mapped DM-RS resource elements of received signal at DRU1 and DRU2.