Adaptive TDD Configuration Based on Load and Channel Quality for Type-1 Inband RN in LTE-A

Chun-Chuan Yang[1], Jeng-Yueng Chen[2], Yi-Ting Mai[3], Yi-Ming Tsai[1]

[1] Department of Computer Science & Information Engineering, National Chi Nan University, Taiwan
[2] Department of Information & Networking Technology, Hsiuping University of Science & Technology, Taiwan
[3] Department of Sport Management, National Taiwan University of Sport, Taiwan
ccyang@csie.ncnu.edu.tw, jychen@hust.edu.tw, wkb@ntupes.edu.tw, mkso5505@gmail.com

Abstract

LTE-Advanced (LTE-A) is one of the radio access technology standards developed by the Third Generation Partnership Project (3GPP), and it is also the most popular standard of 4G/5G mobile communications technology at present. In order to extend the coverage area and provide higher transmission rates for users at the cell edge, the idea of *Relay Node* (RN) was proposed in LTE-A. On the other hand, two duplex modes are defined in LTE-A, namely *frequency division duplex* (FDD) and *time division duplex* (TDD), for transmission in both the uplink (UL) and downlink (DL) directions. In this paper, dynamic TDD configuration for Type-1 inband RN is addressed. Based on the input load and the channel quality, four basic schemes under the top-down and bottom-up strategies are proposed to select a proper configuration for the backhaul link and the access links. Enhanced versions of the basic schemes are also proposed, which alternate among two or three configurations in order to maximize the total capacity in the network. Simulation study demonstrates the benefit of the top-down schemes in terms of higher throughput than bottom-up schemes as well as the contrast scheme of random selection. Enhanced schemes can achieve even higher throughput than their counterpart basic schemes.

Keywords: LTE-A, Relay node, TDD configuration

1 Introduction

As a major 4G/5G system, *Long-Term Evolution* (*LTE*) (3GPP, 2008) [1] and its enhancement namely *LTE-Advanced* (*LTE-A*) (3GPP, 2011) [2] have become the fastest developing mobile communications technology in recent years phasing out 2G and 3G cellular radio methods. Compared with its previous version of Release 8, LTE-A (Release 10 and up) aims to provide higher capacity and speed with some enhanced features including *Carrier Aggregation*, *Multiple Input and Multiple Output Antenna*, *Coordinated Multipoint Transmission and Reception*, and *Relay Node* (RN). LTE-A can provide up to 1 Gbps peak data rate in the downlink and 500 Mbps in the uplink over wide frequency bandwidths (up to 100 MHz), in which the *uplink* (UL) is defined for the transmission from the user equipment (denoted by *UE*) to the base station (denoted by *eNodeB*), and the *downlink* (DL) is defined for the transmission from eNodeB to UE.

Introduction of RN in LTE-A enhances both coverage and capacity. There are two basic types of RN that are proposed, namely *Type-1* and *Type-2*. Type-2 RNs do not have their own cell identity and look just like the main cell. Any UE in range is not able to distinguish a Type-2 RN from the main eNodeB within the cell. A Type-1 RN controls its cell with its own identity including the transmission of the synchronization channels and reference symbols, and appears as if it is a Release 8 eNodeB to Release 8 UEs to ensure backwards compatibility. With the presence of RN, the radio link between the base station and UE has become two hops. The link between the base station (called the donor eNodeB or DeNB) and RN is referred to as the *backhaul link*, while the link between RN and UE is referred to as the *access link*. With respect to the usage of spectrum, Type-1 RN's operation can be divided into *inband* and *outband* types. A Type-1 RN is said to be inband if the backhaul link and the access link are on the same carrier frequency, outband if not.

On the other hand, in order for radio communications systems to be able to communicate in DL and UL directions it is necessary to have a duplex scheme. There are two forms of duplex defined in LTE-A, namely *frequency division duplex* (*FDD*) and *time division duplex* (*TDD*). FDD implies that DL and UL transmission take place in different, sufficiently separated, frequency bands. In TDD, there is a single frequency band only and UL and DL transmissions are separated in the time domain on a cell basis. Different asymmetries in terms of the amount of resources, i.e. subframes, allocated for UL and DL transmission

*Corresponding Author: Jeng-Yueng Chen; E-mail: jychen@hust.edu.tw
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respectively are provided through the seven different DL/UL configurations within a radio frame (10ms), which allows the network to cope with asymmetric traffic loads.

In this paper, the issue of dynamic TDD configuration for Type-1 inband RN is addressed. Based on the traffic load and the channel quality, two strategies namely top-down and bottom-up each with associated schemes are proposed. As demonstrated by the simulation study, higher throughput can be achieved by the proposed top-down schemes. The remainder of the paper is organized as follows. In section 2, a brief survey of LTE-A TDD as well as related research is presented. Proposed schemes of dynamic TDD configuration including four basic schemes and four enhanced schemes are presented in section 3. Performance evaluation is presented in section 4. Finally, section 5 concludes this paper.

2 Related Work

Seven configurations of TDD for the radio link between the eNodeB and UEs are defined in LTE-A as displayed in Table 1, in which different numbers of DL and UL subframes are specified within a radio frame of 10ms in order to provide some flexibility in resource management for both directions. The switch between DL and UL occurs in the special subframe (denote by S in Table 1), which is split into three parts: a downlink part (DwPTS), a guard period (GP), and an uplink part (UpPTS). The DwPTS can be treated as a DL subframe that can be used to transmit a smaller amount of data than a regular subframe. The UpPTS, however, is not used for data transmission due to the very short duration. Instead, it can be used for channel sounding or random access. It can also be left empty, in which case it serves as extra guard period.

Table 1. TDD Configuration in LTE

DL/UL configuration	Subframe number									
	0	1	2	3	4	5	6	7	8	9
0	D	S	U	U	U	D	S	U	U	U
1	D	S	U	U	D	D	S	U	U	D
2	D	S	U	D	D	D	S	U	D	D
3	D	S	U	U	U	D	D	D	D	D
4	D	S	U	U	D	D	D	D	D	D
5	D	S	U	D	D	D	D	D	D	D
6	D	S	U	U	U	D	S	U	U	D

Note. D: DL subframe, U: UL subframe, S: Special subframe.

With the presence of Type-1 inband RNs in the mode of TDD, in order to ensure the RN is not transmitting on the access link while it is receiving on the backhaul link, some subframes should be reserved for the backhaul link. For the UL transmission, the scheduler in the RN can block UE uplink transmission through the UL grant scheduling. But for the DL transmission, the UEs are always expecting the control data on PDCCH (Physical Downlink Control Channel) in every subframe. Therefore, to reserve blank subframe for the backhaul link, a specific frame, which was originally designed for MBSFN (Multicast Broadcast Single Frequency Network), is used. MBSFN subframe includes control data while most of the frames are targeted for multicast transmission. In a MBSFN subframe, UEs expect cell-specific reference signals and control signaling to be transmitted only in the first or two OFDM (Orthogonal Frequency-Division Multiplexing) symbols, which means that the remain part of the subframe can be empty. By configuring some subframes as MBSFN subframes, the RN can stop transmitting on the data region of these subframes and receive from the DeNB on the backhaul link.

Due to the requirement of Type-1 inband RN in TDD that a subframe can only be used for the backhaul or the access link in either direction of DL or UL, as well as the requirement of MBSFN subframes and HARQ (Hybrid Automatic Repeat Request) timing, there are 19 configurations specified by 3GPP for the backhaul link [3-4], as displayed in Table 2. Note that subframes 0~1 and 5~6 cannot be configured as MBSFN subframes, therefore they are ineligible to be used by the backhaul link, resulting that the configuration of the relay cell (i.e. the access link) in Table 2 does not include Configurations 0 and 5.

Interference mitigation is one of the main challenges in LTE TDD. Under the assumption that all cells in the network are required to follow the same TDD configuration, adaptive optimization of TDD configuration based on UL and DL traffic in different cells was investigated in [5]. A power control scheme for non-uniform TDD configurations in the network was proposed in [6], in which eNodeB adjusts the transmit power in some specific DL subframes to reduce co-channel interference. Dynamic configuration and interference mitigation for coexisting FDD and TDD systems was also addressed in the literature [7-8]. For the case of Type-1 inband RN in LTE-A TDD, system resources partitioning as well as transmission scheduling for DL transmission from DeNB to RNs and macro UEs were addressed in order to achieve high throughput while maintaining a certain level of fairness [9-11]. An inter-cell co-channel interference mitigation scheme in LTE-A relay systems was proposed in [12], in which the backhaul subframe allocation timing is coordinated among macro and relay cells. Transmission power control for interference mitigation in small cell networks was addressed in [13] and [14]. Some other researches focused on dynamic TDD reconfiguration for heterogeneous networks (HetNet) [15-18].

Table 2. Backhaul and relay cell configuration in LTE-A TDD

Backhaul subframe configuration	Configuration in relay cell	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	1					D				U	
1					U						D
2						D				U	D
3					U	D					D
4					U	D				U	D
5	2			U						D	
6					D				U		
7				U		D				D	
8					D				U		D
9				U	D	D				D	
10					D				U	D	D
11	3				U				D		D
12					U				D	D	D
13	4				U						D
14					U				D		D
15					U					D	D
16					U				D	D	D
17					U	D			D	D	D
18	6					U					D

3 Dynamic TDD Configuration Schemes

We focus on the network environment of a DeNB with multiple Type-1 inband RNs and all UEs are connected to an RN as displayed in Figure 1. The cell coverage area of the DeNB is called the *macro cell*, and the cell coverage area of each RN is called a *relay cell*. The goal of a dynamic TDD configuration scheme is to select a proper configuration from Table 2 for the backhaul link as well as the access links (relay cells). The basic idea of the proposed schemes in this paper is firstly calculating the subframe demand for the backhaul link and the access links and then selecting the appropriate configuration for all the demands.

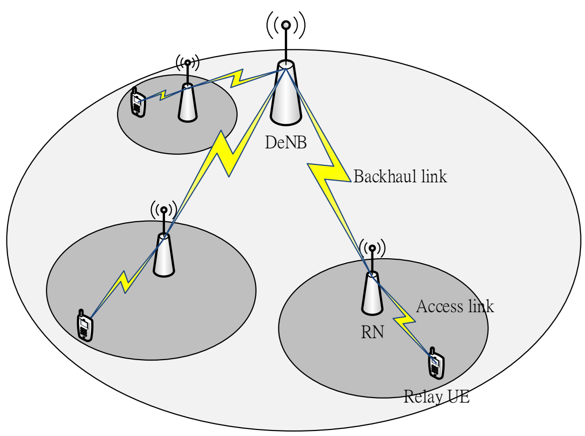

Figure 1. LTE-A Type-1 RN network

There are two directions in determining the final configuration for the network: *top-down* or *bottom-up*. In the top-down approach, the subframe demand of the backhaul link is firstly used to determine the candidate configurations and the subframe demands of the access links are then used to select the final configuration for the network. Reversely, in the bottom-up approach, the subframe demand of the access links are considered first and then the backhaul link. Two different basic schemes under each approach are proposed and therefore four basic TDD configuration schemes are proposed in this paper, namely *TD-Avg*, *TD-Vote*, *BU-Avg*, and *BU-Vote*. Moreover, instead of choosing only one TDD configuration, enhanced schemes that alternate among a couple of TDD configurations for the calculated subframe demand are also proposed. In the following, the calculation of the subframe demand for the backhaul link and the access links is presented followed by the four basic schemes and the four enhanced schemes.

3.1 Subsection

The subframe demand is the average number of subframes in a radio frame (10ms) required for data transmission. The information needed to calculate the subframe demand includes the average input load and the average channel capacity. The DeNB and the RNs are assumed to be able to collect and measure the load information for UL and DL transmissions. The average channel capacity for the backhaul link and the access links are calculated according to CQI feedbacks on the links. Detail calculation of the average channel capacity in LTE can be found in the authors' previous work [19]. The parameters used in calculating the subframe demand are defined in Table 3.

Table 3. Parameters used in calculation of the subframe demand

Notation	Definition
N	Number of RNs in the macro cell
λ_i^{DL} , λ_i^{UL}	DL/UL data rate for RN_i (bits per radio frame), $i = 1 \sim N$
$C_i^{DL, BK}$, $C_i^{UL, BK}$	DL/UL backhaul link channel capacity for RN_i (bits per radio frame)
$C_i^{DL, AC}$, $C_i^{UL, AC}$	DL/UL access link channel capacity for RN_i (bits per radio frame)
$D^{DL, BK}$, $D^{UL, BK}$	DL/UL subframe demand on the backhaul link (# subframe)
$D_i^{DL, AC}$, $D_i^{UL, AC}$	DL/UL subframe demand on the access link of RN_i (# subframe)
$D_{Avg}^{DL, AC}$, $D_{Avg}^{UL, AC}$	Average DL/UL subframe demand for all access links (# subframe)

The subframe demand for DL transmission on the backhaul link is calculated as the summation of the DL subframe demand for each RN on the backhaul link, i.e.

$$D^{DL, BK} = \sum_{i=1}^{N} \left(\frac{\lambda_i^{DL}}{c_i^{DL, BK}}\right) \quad (1)$$

$$D^{UL, BK} = \sum_{i=1}^{N} \left(\frac{\lambda_i^{UL}}{c_i^{UL, BK}}\right) \quad (2)$$

The DL/UL subframe demand for each RN on the access link and the average DL/UL subframe demand for all access links are calculated as follows.

$$D_i^{DL, AC} = \frac{\lambda_i^{DL}}{c_i^{DL, AC}} \quad (3)$$

$$D_i^{UL, AC} = \frac{\lambda_i^{UL}}{c_i^{UL, AC}} \quad (4)$$

$$D_{Avg}^{DL, AC} = \left(\sum_{i=1}^{N} D_i^{DL, AC}\right) / N \quad (5)$$

$$D_{Avg}^{UL, AC} = \left(\sum_{i=1}^{N} D_i^{UL, AC}\right) / N \quad (6)$$

3.2 Basic Top-Down Schemes

The calculated subframe demands on the backhaul link and the access links are used to match a proper TDD configuration. For the sake of compactness, we summarize the number of DL and UL subframes (#DL, #UL) in each configuration from Table 2 and Table 1 and assign a setting ID to different pair of (#DL, #UL) as displayed in Table 4 and Table 5. Note that the special subframe in Table 1 is seen as a DL subframe for simplicity.

Table 4. Setting for backhaul subframe configuration

Backhaul Configuration	0	1	2	3	4	5	6	7	8	9	10
(#DL, #UL)	(1,1)		(2,1)		(2,2)	(1,1)		(2,1)		(3,1)	
Denoted by	W1		W2		W5	W1		W2		W3	

Backhaul Configuration	11	12	13	14	15	16	17	18
(#DL, #UL)	(2,1)	(3,1)	(1,1)	(2,1)		(3,1)	(4,1)	(1,1)
Denoted by	W2	W3	W1	W2		W3	W4	W1

Table 5. Setting for relay cell configuration

Configuration in Relay Cell	1	2	3	4	6
(#DL, #UL)	(4,6)	(8,2)	(7,3)	(8,2)	(5,5)
Denoted by	Z2	Z4	Z3	Z4	Z1

The first step in the top-down schemes is to find the best fit setting of (#DL, #UL) among W1~W5 for the calculated subframe demands on the backhaul link. That is, given the pair of ($D^{DL, BK}$, $D^{UL, BK}$), the best fit is the closest setting in Euclidean distance. For example, if the calculated subframe demands on the backhaul link is (2.3, 1.2), the best fit for the demands is W2 as displayed in Figure 2.

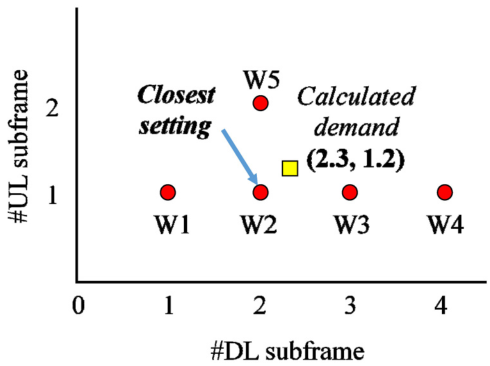

Figure 2. E.g. Step 1 in the top-down schemes

The second step in the top-down schemes is to determine a common setting for all access links according to the calculated subframe demands of the access links. The available settings (candidates) for the access link depends on the setting on the backhaul link from the first step. For example, given the setting of W2 for the backhaul link, the available settings for the access link are Z2, Z3, and Z4 according to Table 4 and Table 2. The available settings for backhaul settings W1~W5 are summarized in Table 6.

Table 6. Available access link settings for a given backhaul setting

Backhaul Setting	Available Settings for the access link
W1	Z1, Z2, Z4
W2	Z2, Z3, Z4
W3	Z2, Z3, Z4
W4	Z4
W5	Z2

Considering different relay cells may have different subframe demands on the access link, two schemes namely *TD-Avg* and *TD-Vote* are proposed to select a proper setting for all access links. In *TD-Avg*, the closest setting for the average subframe demand ($D_{Avg}^{DL,AC}$, $D_{Avg}^{UL,AC}$) is selected. In *TD-Vote*, each RN votes for its best (closest) setting and the load of the relay cell (i.e. $\lambda_i^{DL} + \lambda_i^{UL}$ for RN_i) is assigned as the weight of RN's vote. The setting with the most weighted vote is selected as the common setting for all access links in *TD-Vote*. For the example in Figure 3 and given W2 is selected for the backhaul link, Z3 is selected by *TD-Avg* as the setting for the access links, and Z2 is selected by *TD-Vote*.

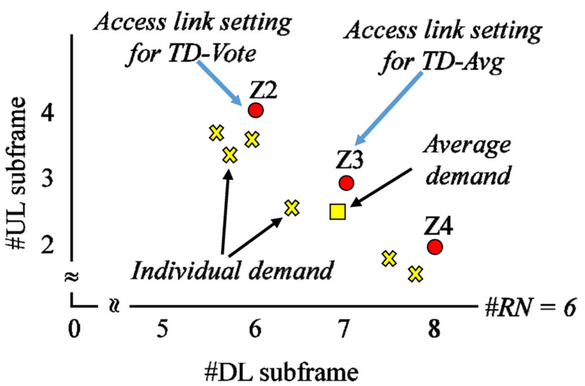

Figure 3. E.g. Step 2 in the top-down schemes

The final configuration can be decided as the setting for the backhaul link and the setting for the access links are selected. For instance, the setting of W2 for the backhaul link and the setting of Z3 for the access links lead to *Configuration 11* for the backhaul link associated with *Configuration 3* for the relay cells according to Table 2. The setting of W2 for the backhaul link and the setting of Z2 for the access links lead to *Configuration 2* or *Configuration 3* for the backhaul link associated with *Configuration 1* for the relay cells.

3.3 Basic Bottom-Up Schemes

In the bottom-up schemes, a common access link setting is first determined according to the subframe demands of all access links. As in the top-down approach, there are two proposed bottom-up schemes namely *BU-Avg* and *BU-Vote*. In *BU-Avg*, the closest setting for the average subframe demand ($D_{Avg}^{DL,AC}$, $D_{Avg}^{UL,AC}$) is selected. In *BU-Vote*, the setting with most weighted votes is selected. Figure 4 shows examples of *BU-Avg* and *BU-Vote* in selecting a common setting for the access links. The second step is to select the setting for the backhaul link according to the subframe demand on the backhaul link, i.e. ($D^{DL,BK}$, $D^{UL,BK}$). The closest one among the available backhaul settings to the subframe demand is selected as the backhaul setting. Available settings for a given access link setting are summarized in Table 7. Final configuration of the backhaul link and the access links are decided accordingly.

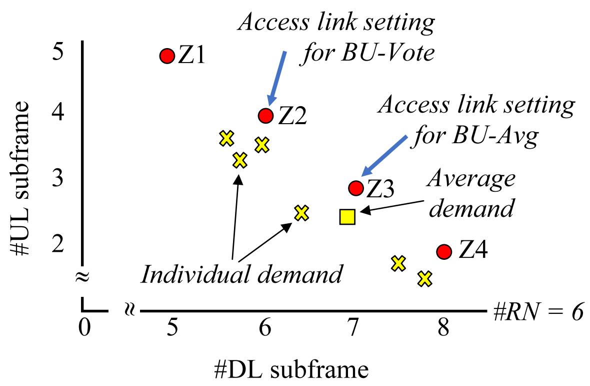

Figure 4. E.g. Step 1 in the bottom-up schemes

Table 7. Available backhaul settings for a given access link setting

Backhaul Setting	Available Settings for the access link
Z1	W1
Z2	W1, W2, W5
Z3	W2, W3
Z4	W1, W2, W3, W4

3.4 Enhanced Schemes

Considering the first step in the basic top-down schemes, we observe that there is usually no perfect setting for a given subframe demand on the backhaul link. Taking the case in Figure 2 as an example, the subframe demand of (#DL, #UL) = (2.3, 1.2) cannot be met by selecting the closest setting of W2 (2, 1). On the other hand, selecting W3 (3, 1) can only meet the DL demand and selecting W5 (2, 2) can only meet the

UL demand. That is, by selecting a single setting cannot completely satisfy the given subframe demand. However, if we can select multiple settings and alternate among the settings over a period of time, not only can we meet the subframe demand but also we can reduce the problem of over-allocation. For example, given the subframe demand of (2.3, 1.2) and within a cycle of 100 radio frames, a perfect solution is to select W2 (2, 1) for 50 radio frames, W3 (3, 1) for 30 radio frames, and W5 (2, 2) for 20 radio frames. It can be easily verified that the total allocated DL/UL subframes in the perfect solution are equal to the total demand over 100 radio frames (no more, no less). The main idea of the enhanced schemes is therefore to select more than one settings for a given subframe demand and alternate among the selected settings not only for meeting the demand but also for better utilization of the capacity.

For enhanced top-down schemes, according to the available settings of W1~W5 in the first step, the space of the subframe demand is divided to 10 zones (denoted by *zone A* ~ *zone J*) as displayed in Figure 5. The settings surrounding the zone where the subframe demand is located are selected in the enhanced schemes. For example, subframe demand of (2.3, 1.2) is located in *zone H*, and W2, W3, and W5 are selected in the enhanced schemes. Note that there are three types of zone in Figure 5: zones with 3 settings (*zone G, H, I*), zones with 2 settings (*zone B, C, D, F, J*), and zone with only 1 setting (*zone A, E*). For subframe demand located in a zone with only 1 setting, the enhanced schemes are the same with the basic scheme. For subframe demand located in a zone with 3 or 2 settings, the enhanced schemes calculate the length of the time period over which each setting is selected. The calculation of the time length for each setting is formalized as an optimization problem with the notations listed as follows:

K: the cycle length (in radio frames) configured by the enhanced schemes.

G_{DL}, G_{UL}: the total number of DL/UL subframes allocated over *K* radio frames.

R_{DL}, R_{UL}: the total number of DL/UL subframe demand over *K* radio frames.

Δ_{DL}, Δ_{UL}: the deficit of DL/UL subframes over *K* radio frames.

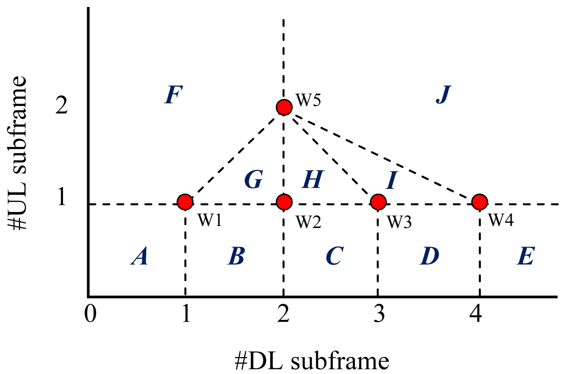

Figure 5. Zones of enhanced top-down schemes

Since the calculation is similar for zones with 2 settings and 3 settings, only the case of 3 settings is presented. Given the subframe demand of (x_0, y_0) located in a zone with three settings namely S_1 (x_1, y_1), S_2 (x_2, y_2), and S_3 (x_3, y_3). We assume the time length for selecting S_1 is T_1 radio frames, T_2 radio frames for S_2, and T_3 radio frames for S_3, where $T_1+T_2+T_3 = K$ radio frames and T_1, T_2, T_3 are integers no less than zero. The deficit of DL/UL subframes over *K* radio frames is calculated as follows:

$$\Delta_{DL} = \begin{cases} R_{DL} - G_{DL}, \text{if } R_{DL} > G_{DL} \\ 0, \text{otherwise} \end{cases} \quad (7)$$

$$\Delta_{UL} = \begin{cases} R_{UL} - G_{UL}, \text{if } R_{UL} > G_{UL} \\ 0, \text{otherwise} \end{cases} \quad (8)$$

where $R_{DL} = K \times x_0$, **(9)**

$$R_{UL} = K \times y_0, \quad (10)$$

$$G_{DL} = (T_1 \times x_1 + T_2 \times x_2 + T_3 \times x_3), \quad (11)$$

$$G_{UL} = (T_1 \times y_1 + T_2 \times y_2 + T_3 \times y_3) \quad (12)$$

The goal is to find the value of T_1, T_2, and T_3 to minimize the summation of the deficit of DL and UL subframes, ($\Delta_{DL} + \Delta_{UL}$), over *K* radio frames. If there are multiple solutions to the optimization problem, one of the solutions is randomly selected as the final choice. Note that the first step in the two basic top-down schemes is the same, which is also true in the enhanced top-down schemes. Once the settings and the corresponding time length for the backhaul link are determined in the first step of the enhanced top-down schemes, the second step is to select a common setting for the access links. As in the basic schemes, there are two methods to determine a common setting for the access links and results in two enhanced top-down schemes, namely *TD-Avg-Alt* and *TD-Vote-Alt*.

Similarly, the idea of alternating between two settings is also applied to the first step of the enhanced bottom-up schemes. Zone classification for the enhanced bottom-up schemes is displayed in Figure 6, in which the boundary lines between zones are perpendicular to the line passing the four settings of Z1 ~ Z4. Calculation of the time length for each selected settings is similar to that in the enhanced top-down schemes, which leads to the two enhanced bottom-up schemes namely *BU-Avg-Alt* and *BU-Vote-Alt*.

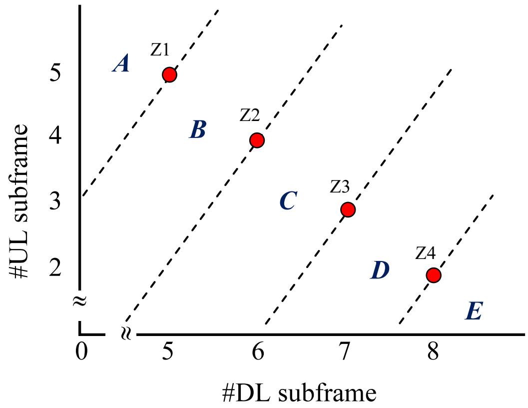

Figure 6. Zones of enhanced bottom-up schemes

4 Performance Evaluation

There are 6 RNs under the DeNB and the total number of UEs in the cell varies from 144 to 1440 in the simulated network. Two types of load distribution among RNs namely *Equal Load* and *Hot Spot* were investigated. In *Equal Load*, each RN is assigned with the same number of UEs. In *Hot Spot*, 2/3 of UEs are assigned to 2 RNs and 1/3 of UEs are assigned to the rest of 4 RNs. Each UE is assumed to have a either UL or DL flow with rate 60Kbps, by which we assume there is only one medium-quality audio stream for each UE. Several cases of different “DL:UL” ratios, including “1:1”, “2:1”, “3:1”, “3.8:1” and “1:2” were simulated. Performance criterion is the total throughput of DL and UL. In addition to the proposed schemes, the scheme of *Random Selection* which randomly selects a TDD configuration from Table 2 was also simulated as the contrast scheme. Simulation parameters are summarized in Table 8.

Table 8. Simulation parameters

Parameter	Value
System Capacity	20MHz (100 RBs)
#RN	6
#UE	144, 288, …, 1440
Backhaul link CQI	15
Access link CQI	6~15
Load Distribution	*Equal Load*, *Hot Spot*
DL:UL	1:1, 2:1, 3:1, 3.8:1, 1:2
Flow Rate	60 Kbps
Contrast Scheme	*Random Selection*

Simulation results of the basic schemes in *Equal Load* with different DL:UL ratios are displayed in Figure 7 ~ Figure 11. Given the similar results for *Hot Spot* as *Equal Load* in the cases of 1:1 and 2:1, only the results for the ratio of 2:1, 3:1, and 3.8:1 in *Hot Spot* are displayed in Figure 12 ~ Figure 14. Some observations can be made from the figures:

(1) *TD-Avg* and *TD-Vote* outperform the contrast scheme of *Random Selection* as well as the bottom-up schemes of *BU-Avg* and *BU-Vote* in terms of total DL and UL throughput. The reason is that the top-down schemes tend to select a more appropriate setting on the backhaul link other than the access links, and the backhaul link plays a more important role in throughput than the access links. The bottom-up schemes tend to select an appropriate setting for the access links, which may lead to an inappropriate backhaul setting. As a result, the performance of the bottom-up schemes is even worse than that of *Random Selection* in some cases.

(2) Since the difference of *TD-Avg* and *TD-Vote* lies in the selection of the access link setting, the two top-down schemes always select the same backhaul setting, which limits the available settings for the access links. Therefore, the performance results of *TD-Avg* and *TD-Vote* are almost the same in the simulation.

(3) In the case of *Equal Load*, *BU-Avg* and *BU-Vote* select the same setting for the access links and therefore lead to almost the same performance results. In the case of *Hot Spot* as displayed in Figure 12 and Figure 13, *BU-Vote* has a better chance to select a more appropriate setting for the access links than *BU-Avg*. Therefore, *BU-Vote* outperforms *BU-Avg* in some cases under the load distribution pattern of *Hot Spot*.

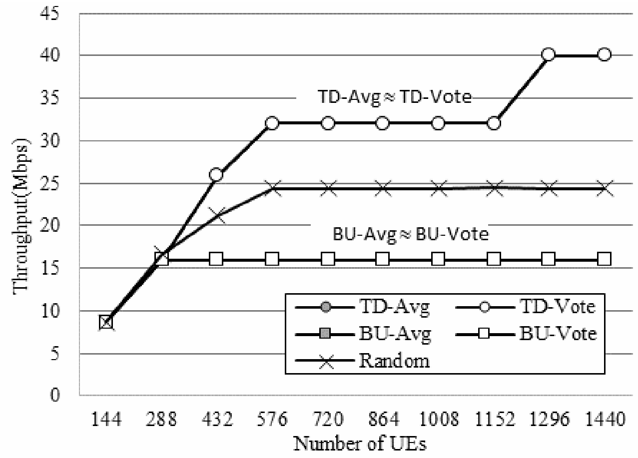

Figure 7. Basic, *Equal Load*, DL:UL = 1:1

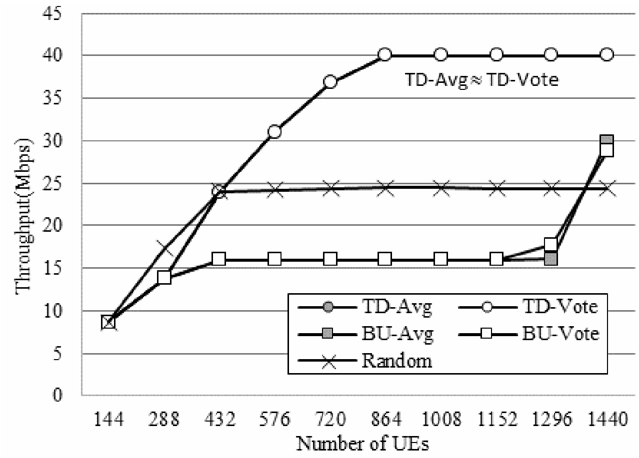

Figure 8. Results of *Equal Load*, DL:UL = 2:1

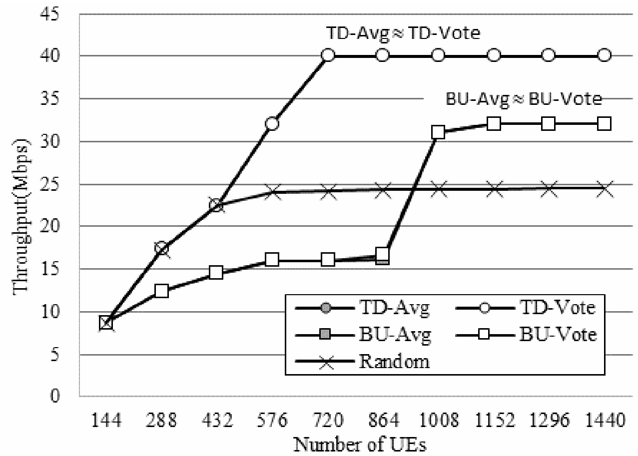

Figure 9. Basic, *Equal Load*, DL:UL = 3:1

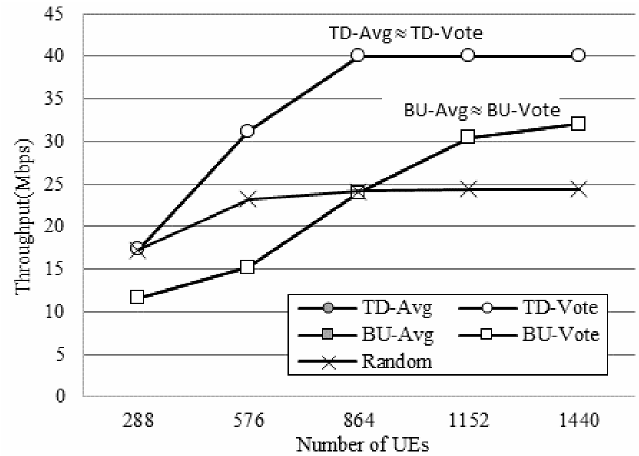

Figure 10. Basic, *Equal Load*, DL:UL = 3.8:1

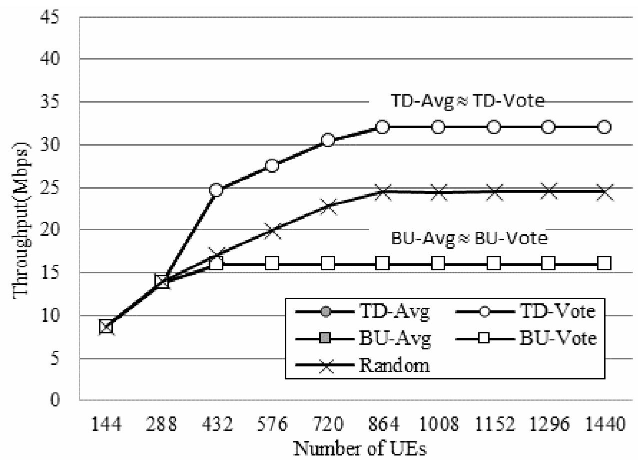

Figure 11. Basic, *Equal Load*, DL:UL = 1:2

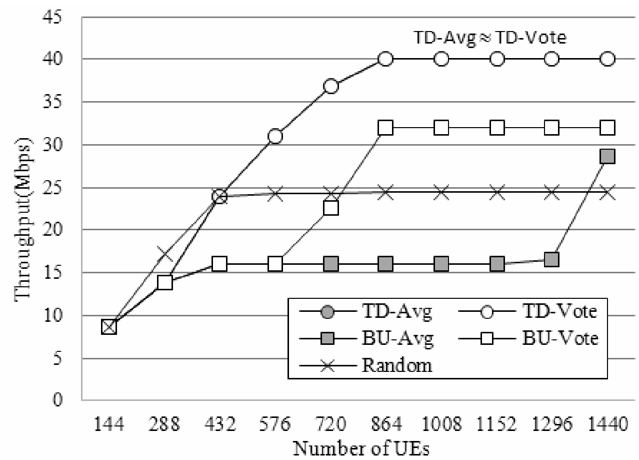

Figure 12. Basic, *Hot Spot*, DL:UL = 2:1

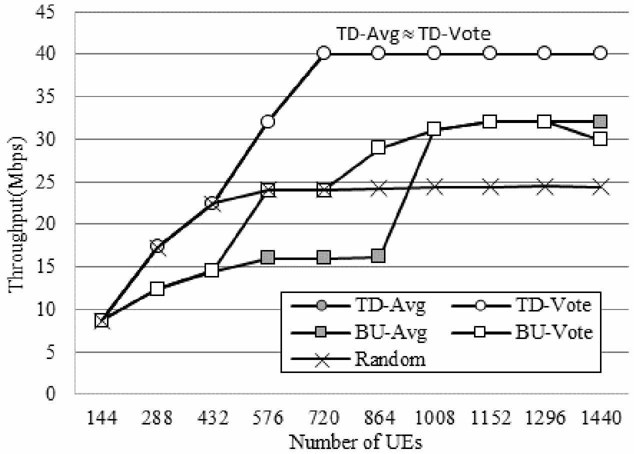

Figure 13. Basic, *Hot Spot*, DL:UL = 3:1

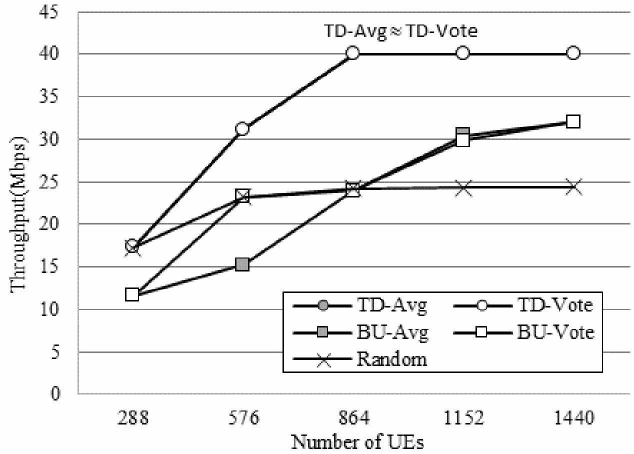

Figure 14. Basic, *Hot Spot*, DL:UL = 3.8:1

Simulation results of the enhanced schemes comparing with the basic schemes are displayed in Figure 15 ~ Figure 19 for *Equal Load* and Figure 20 ~ Figure 22 for *Hot Spot*. Given that the results of *TD-Avg-Alt* and *TD-Vote-Alt* are similar in both *Equal Load* and *Hot Spot*, only results of *TD-Avg-Alt* are displayed in the figures. Some observations can be made as follows.

(1) *TD-Avg-Alt* and *TD-Vote-Alt* outperforms their corresponding basic schemes of *TD-Avg* and *TD-Vote* in both *Equal Load* and *Hot Spot* scenarios, demonstrating the benefit of alternating among a couple of appropriate settings in TDD configuration selection.

(2) *BU-Vote-Alt* outperforms *BU-Vote* in a small number of cases in *Equal load*, but there is almost no improvement under the scenario of *Hot Spot*. It is because the benefit of alternating among proper settings for the access links is diluted by the limitation placed by the access link settings in selecting a good enough setting for the backhaul link.

(3) Worse performance of *BU-Avg-Alt* comparing with its basic counterpart of *BU-Avg* is observed in heavy load cases (*#UE* ≥ 1008) in Figures 17, 18, 21 and 22. Moreover, the increase of the number of UEs even results in lower throughput for *BU-Avg-Alt* in some cases. The reason is twofold. Firstly, the method of averaging the subframe demands fails to select proper settings for the access links, and secondly the limitation placed by the access link settings on setting selection for the backhaul link makes the situation even worse.

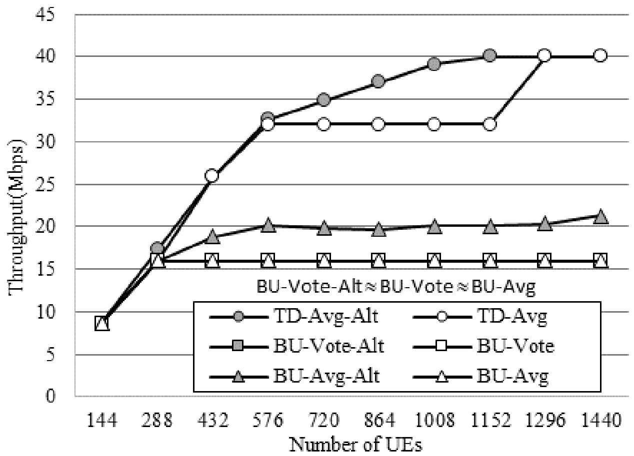

Figure 15. Enhanced, *Equal Load*, DL:UL = 1:1

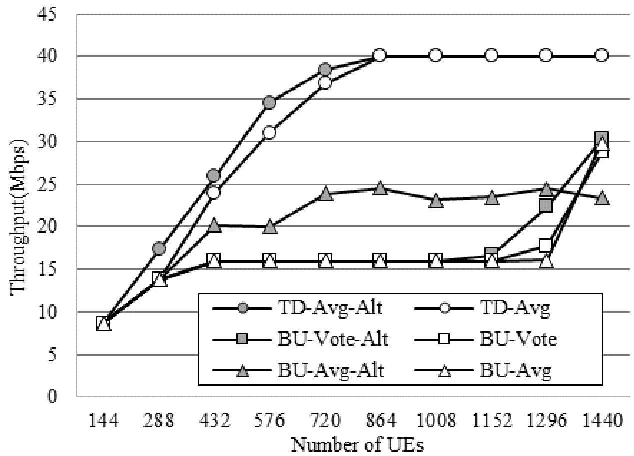

Figure 16. Enhanced, *Equal Load*, DL:UL = 2:1

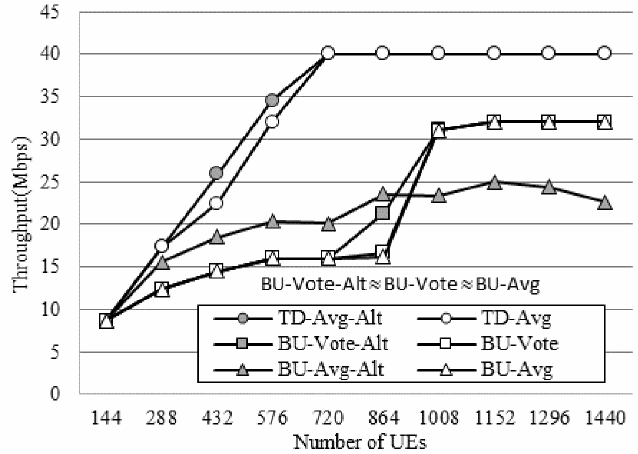

Figure 17. Enhanced, *Equal Load*, DL:UL = 3:1

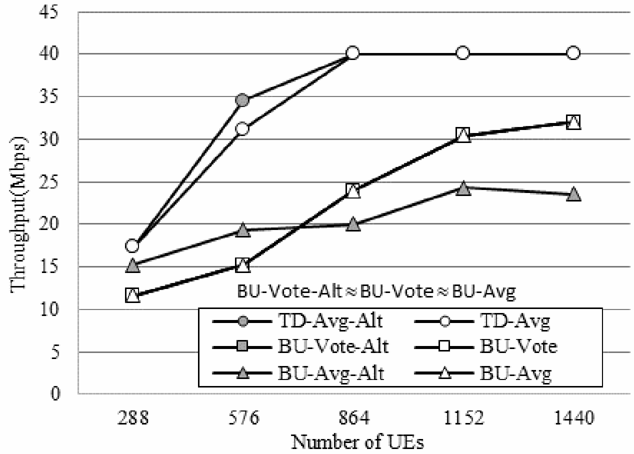

Figure 18. Enhanced, *Equal Load*, DL:UL = 3.8:1

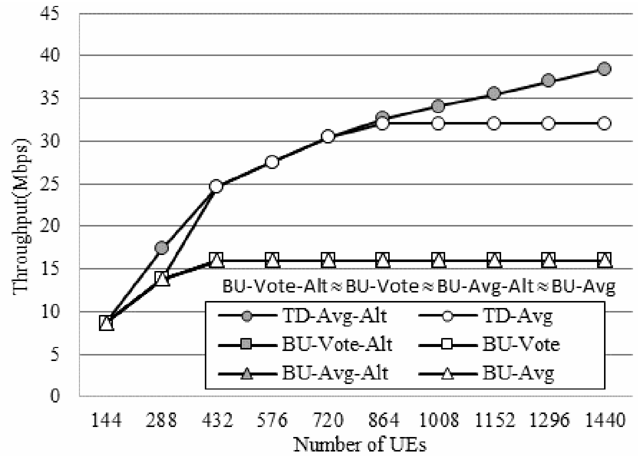

Figure 19. Enhanced, *Equal Load*, DL:UL = 1:2

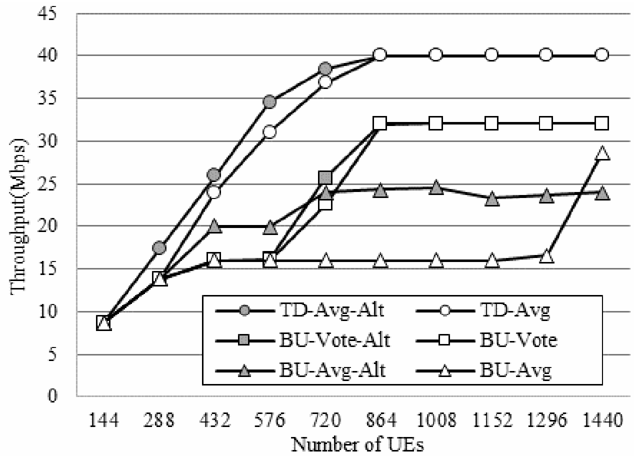

Figure 20. Enhanced, *Hot Spot*, DL:UL = 2:1

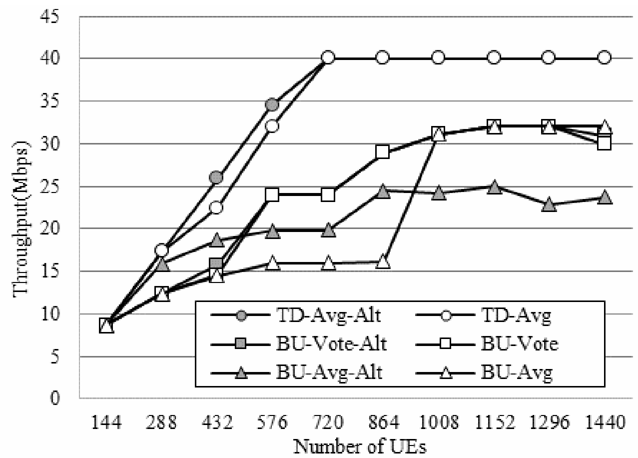

Figure 21. Enhanced, *Hot Spot*, DL:UL = 3:1

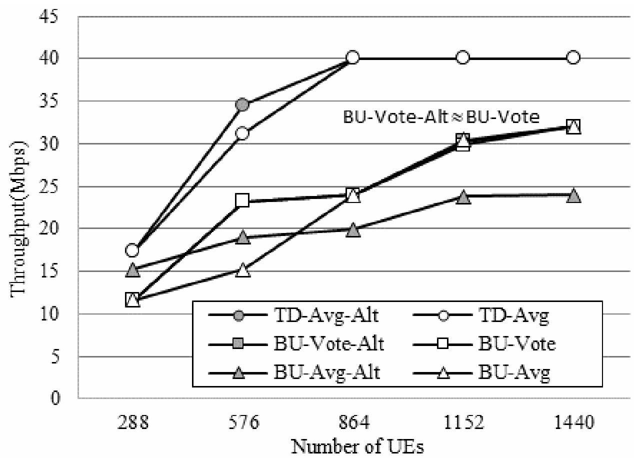

Figure 22. Enhanced, *Hot Spot*, DL:UL = 3.8:1

5 Conclusion

In this paper, dynamic TDD configuration for multiple Type-1 inband RNs in LTE-A is addressed. The subframe demand, calculated according to the input load and the link quality, is used to select the configuration on the backhaul link and the access links. Two top-down schemes, *TD-Avg* and *TD-Vote*, and two bottom-up schemes, *BU-Avg* and *BU-Vote*, are proposed in this paper, in which the backhaul setting is determined first and then the setting for the access links in the top-down schemes, and reversely in the bottom-up schemes. Two sub-schemes (*Avg* and *Vote*) are designed under the top-down and the bottom-up approach in selecting a common access link setting by either the method of *averaging* (*Avg*) or *voting* (*Vote*) for difference subframe demands on the access links. Given that a single TDD configuration cannot fully satisfy the subframe demand, enhanced versions of the basic schemes, namely *TD-Avg-Alt*, *TD-Vote-Alt*, *BU-Avg-Alt*, and *BU-Vote-Alt*, which alternate a couple of configurations for the estimated demand are proposed. Simulation study shows that the top-down schemes are better than the bottom-up schemes and the contrast scheme of *Random Selection* in terms of total downlink and uplink throughput, which indicates the importance of backhaul setting over the setting for the access links. In addition, the performance is further improved by the enhanced top-down schemes of *TD-Avg-Alt* and *TD-Vote-Alt* comparing with their corresponding basic schemes as well as the bottom-up schemes. Lastly, although it is assumed that all UEs are connected to RN in the paper, the proposed schemes can be easily extended to support the case that some UEs are connected to DeNB. Since the UEs connected to DeNB share the same TDD resource with RNs, the input load and the channel quality of the UEs connected to DeNB should also be considered in determining the setting of the backhaul link.

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Biographies

Chun-Chuan Yang received his Ph.D. degree in computer science from National Taiwan University in 1996. He joined the Department of Computer Science and Information Engineering, National Chi-Nan University, Puli, Taiwan in Aug. 1998. His research area of interests includes computer network protocols, mobile and wireless networking, and multimedia networking applications.

Jeng-Yueng Chen received his Ph.D. degree in computer science from National Chi Nan University, Puli, Taiwan, in 2010. He joined the Department of Information Networking Technology, Hsiuping University of Science and Technology in 2001. His current research topics cover network protocols, network management, and 4G/5G.

Yi-Ting Mai received his Ph.D. degree in computer science from National Chi Nan University, Puli, Taiwan, in 2008. In 2014, Dr. Mai is an Associate Professor in Department of Sport Management, National Taiwan University of Sport. His current research topics include Internet technology in education, MIS in sport, and LTE/LTE-A.

Yi-Ming Tsai received his B.S. degree in Computer Science from National Chi Nan University, Puli, Taiwan, in 2015 and M.S. degree in Computer Science from National Chi Nan University, Puli, Taiwan, in 2016. His current research topic includes improving throuhgput in Type-1 relay LTE-A network.