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# A Study on Channel Estimation Algorithm with Sounding Reference Signal for TDD Downlink Scheduling

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***Abstract*—Coping with the limited amount of available spectrum, time division duplexing (TDD) system is considered as an attractive duplexing method due to exploiting channel reciprocity as well as flexible resource management. The conventional scheduling scheme is based on the channel quality indicator (CQI) reported from the user equipment (UE) to estimate instantaneous data rates for the scheduling metric calculation. However, CQI is insufficient to reflect the state of the channel variation in terms of frequency and time. Based on the channel reciprocity of TDD systems, we utilize uplink sounding reference signal (SRS) to estimate downlink channel status. However the received SRS power is a result of uplink power control where power control effect should be compensated to estimate channel status in downlink scheduling. In order to solve this problem, we propose the SRS path loss estimation method based on the power headroom report. By using this scheme, the base station (BS) can obtain the compensated signal-to-interference-plus-noise-ratio (SINR) and determine the scheduling metric based on its calculated SINR instead of reported CQI from UE. Simulation results show that the proposed scheduling algorithm outperforms the conventional scheme in total throughput, whereas the fairness index experienced by the proposed algorithm is lesser than of the conventional scheme based on CQI.**

***Index Terms*—Time division duplex (TDD), radio resource management, sounding reference signal, channel estimation, path loss estimation.**

## I. Introduction

The next generation of mobile wireless communication known as 5G is expected to support the rapidly increasing wireless traffic. To fulfill the increasing demand, an efficient radio resource management method is required as well as allocating additional bandwidth. In this vein, a time division duplex (TDD) technique can be considered as promising candidate to tackle the bandwidth challenge. The principle of TDD is to use the same frequency for uplink and downlink but to alternate the transmission direction in time. The TDD system can be implemented on an unpaired band while the frequency division duplex (FDD) system always requires a pair of bands with a reasonable separation between uplink and downlink directions. It will be easier to find new unpaired allocations than paired allocations thereby increasing the scope of applicability for TDD. Furthermore, the resource can be used efficiently, depending on the data traffic of uplink and downlink [1,2]. In 3GPP LTE/LTE-A, there are seven semi-static uplink-downlink (UL-DL) configurations that are defined in [3]. Moreover, the 3GPP has also commenced to consider the support for dynamic TDD technique, which will flexibly assign transmit resources to uplink and downlink communication in each frame [4,5,12].

On one hand, frequency resource allocation shall increase the spectral efficiency and, in turn, the cell capacity, which is a key performance measurement from the operator perspective. Scheduler at base station (BS) is in charge of allocating portions of resources shared among user equipment (UEs). Current scheduling algorithms of LTE/LTE-A systems have been proposed to partially support contrasting objectives like what list couple of them. Some algorithms such as Maximum Throughput (MT) and Modified-Largest Weighted Delay First (M-LWDF) aim to maximize the throughput, while others aim to provide fairness among UEs like Proportional Fairness (PF) and Throughput to Average (TTA) [6,7]. These various scheduling algorithms commonly use the instantaneous data rate that can be achieved by each UE when the resource block groups (RBGs) will be assigned in the scheduled subframe which depends on the channel quality indicator (CQI) reported by the UE. However, the CQI value is calculated based on the average signal-to-interference-plus-noise-ratio (SINR) for the whole frequency band because of signaling overhead. Hence, the relative channel state among RBGs cannot be achieved at BS. Designing accurate channel estimation at the scheduler side is an important task in order to improve the performance of wireless system. TDD system has a high correlation of the fading on the signals between uplink and downlink, known as channel reciprocity [8,9]. The key benefit of channel reciprocity is that channel measurements in one direction may fully or partially be used to predict the other direction, whereas feedback from the UE is mandatory to obtain information about the downlink channel state in the FDD system.

In this regard, uplink sounding reference signal (SRS) is a good reference for downlink channel estimation in TDD systems [9]. Most researches on channel estimation with SRS mainly focus on massive multiple-input multiple-output (MIMO) since the uplink feedback overhead is too large as the increasing number of antennas in BS. In the downlink channel estimation for massive MIMO, the relative channel status among antennas is enough to construct beamforming. However, the estimation of path loss is also important in downlink scheduling as well as relative channel status among RBGs. This is why there is no previous work on channel estimation with SRS for downlink scheduling.

In this paper, we propose the channel estimation algorithm that exploits power headroom report and SRS to estimate path loss and relative channel status, respectively. The received SRS is adopted uplink power control, where the uplink transmits power should not be unnecessarily high to prevent unnecessary interference to neighbour cells [13], thus we only can estimate the relative channel states among resource blocks or subcarriers. In the proposed algorithm, the path loss of SRS is estimated using power headroom report to compensate the power control effect, and then we introduce the scheduling metric decision method with SRS and power headroom report. The proposed algorithm can be utilized regardless of uplink and downlink allocation ratios. When the appropriate TDD configuration is selected based on traffic demands, the efficient resource management is possible in terms of frequency as well as time.

The remainder of this paper is organized as follows: In Section II, we present the LTE-TDD frame structure and subframe configurations, and we introduce the conventional channel state reporting by UE. The proposed downlink scheduling algorithm using SRS is described in Section III, and we performance in Section IV. Finally, concluding remarks are given in Section V.

## II. Overview of LTE TDD System

### A. TDD subframe configuration and structure

The TDD frame structure in the LTE/LTE-A specification shown in Fig. 1 [8]. As the single frequency band is shared in the time domain between UL and DL, the transmission in LTE-TDD is discontinuous. Therefore, all uplink transmissions need to be ready while any downlink transmission is progressed and, conversely, the downlink needs to be totally silent when any of the uplink is transmitting. Switching between transmission directions has a small hardware delay. To consider the resulting switching delay a guard period (GP) is allocated between the downlink and the uplink subframe. As shown in Fig. 1, LTE-TDD introduced a special subframe that is divided into three parts: the downlink pilot time slot (DwPTS), the GP, and the uplink pilot time slot (UpPTS). DwPTS is considered to be a normal downlink subframe carrying control information as well as data. The GP implements the transition from downlink to uplink which has to be sufficiently long to cover the propagation delay of all downlink interferers and the hardware switch off time. Unlike DwPTS, UpPTS has short duration and it is difficult to carry control information and data. Therefore it is primarily intended for SRS transmission from the UE. The flexibility for the different components of the special subframe is summarized in Table I for the normal cyclic prefix [9].

TABLE I
Possible durations configuration for special subframe structure components

| Components | Range of components duration |
|---|---|
| DwPTS | 3-12 OFDM symbols (213-852$\mu$s) |
| GP | 1-10 OFDM symbols (71-710$\mu$s) |
| UpPTS | 1-2 OFDM symbols (71-142$\mu$s) |

The LTE-TDD frame structure can be adjusted to have either 5ms or 10ms DL-UL switch point periodically. LTE-TDD systems provide 7 different semi-static UL-DL configurations of an LTE frame to offer asymmetric DL-UL allocations (see Table II), hence providing DL-UL allocation ratios that vary from 4:6 to 9:1 (the number of DL-UL subframes) [12]. In Table II,"D", "U", and "S" mean downlink, uplink, and special subframe, respectively. The BS can determine one configuration among the configurations based on traffic characteristics. In practice the UL-DL configuration is the same for all cell and is determined at the network level. Knowledge about what UL-DL configuration is used in the cell is essential for the UE to know the location of critical control channels and timing of hybrid-automated repeat request (HARQ).

TABLE II
Uplink-Downlink Configurations [3]

| Config. | Periodicity | Subframe number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 0 | 5ms | D | S | U | U | U | D | S | U | U | U |
| 1 | 5ms | D | S | U | U | D | D | S | U | U | D |
| 2 | 5ms | D | S | U | D | D | D | S | U | D | D |
| 3 | 10ms | D | S | U | U | U | D | D | D | D | D |
| 4 | 10ms | D | S | U | U | D | D | D | D | D | D |
| 5 | 10ms | D | S | U | D | D | D | D | D | D | D |
| 6 | 5ms | D | S | U | U | U | D | S | U | U | D |

### B. Uplink channel state reporting

In LTE/LTE-A, the UE sends CQI report as an indication of the data rate which can be supported by the downlink channel. The CQI reported values are used by the BS for downlink scheduling and link adaptation, which are important features of LTE. The BS selects the proper modulation and coding scheme (MCS) based on CQI to maximize the supported throughput for a given target block error rate (BLER). CQI is 4-bit integer and is based on the observed SINR at the UE using the downlink reference signal. The UE has a look up table as to tell what SINR maps to what CQI. Once done, UE reports this CQI over physical uplink control channel (PUCCH) or physical uplink shared channel (PUSCH). There are two kinds of channel quality estimations [14]: One is the wideband estimation, where a single CQI value is decided for the whole bandwidth, and the other is the subband estimation, where the CQI is decided for each bandwidth part that depends on system bandwidth. CQI report is determined to find the

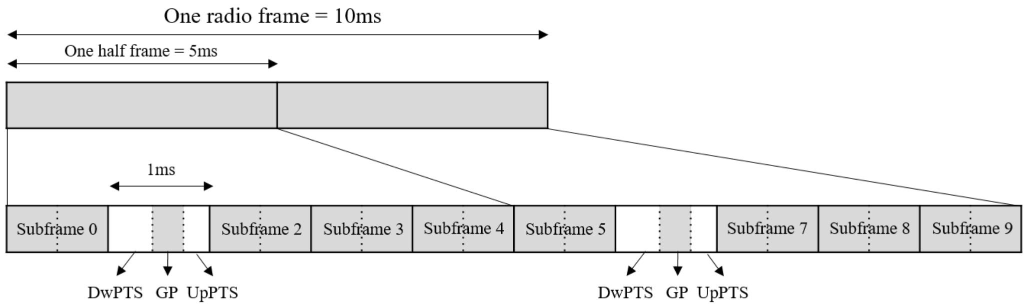


Fig. 1. LTE-TDD frame structure

balance between resolution of channel quality estimation and the amount of signaling overhead. Therefore, the accuracy of channel estimation with CQI is insufficient to reflect the channel status.

## III. Proposed LTE-TDD scheduling algorithm

In this section, we introduce the proposed path loss estimation method based on power headroom report and calculate the metric for downlink scheduling with SRS as well as power headroom report.

### A. Downlink channel estimation using SRS

Exploring reciprocity property of the wireless link, in TDD the uplink and downlink channels work on the same carrier frequency. Thus, we can use the uplink channel to estimate the downlink channel without feedback such as CQI. SRS could be an efficient reference to enable downlink channel estimation. In LTE/LTE-A, the SRS configuration is cell-specific. In the frequency domain, SRS transmission should cover the frequency band that is of interest for the scheduler. By means of a full bandwidth SRS transmission that allows the sounding of the entire frequency band of interest with a single SRS transmission [14]. Hence, the channel estimation with uplink SRS can obtain higher accuracy than the current scheme with the CQI for various frequencies and/or time selective fading channels [15].

In this paper, we propose a downlink channel estimation for scheduling by using SRS that is not applied directly to the downlink scheduling since uplink power control is carried out to compensate the path loss to BS. With the power controlled SRS, the relative channel status information among the RBGs is obtained, but the absolute path loss or channel status is unknown. In order to estimate the path loss of power controlled SRS, we exploit the power headroom report. The original role of power headroom report is to assist the scheduler in the selection of a combination of MCS and resource block size that does not lead to the UE being power limited [13].

First of all, prior to estimating the SRS path loss at the BS, the operation of the transmitting SRS and power headroom report in the UE is shown in sequence.

- UE's step 1 : Uplink transmitter power control used to provide an appropriate transmit power to the desired signals to achieve the necessary quality. In order to achieve these goals, the UE has to adapt to the radio propagation channel conditions, including path loss. It is calculated in the UE based on the reference symbol received power (RSRP) [9].
- UE's step 2: LTE uplink power control is carried out with a combination of an open-loop mechanism, implying that the UE transmit power depends on estimation of the downlink path loss, and a closed-loop mechanism, implying that the BS adjusts the UE transmit power by means of explicit power control commands transmitted on the downlink control signal [13]. These power control commands are determined based on prior network measurements of the received power of uplink signal. The SRS transmit power basically follows that of the physical uplink shared channel (PUSCH). Thus, the power control for SRS transmission can be described by the following expression:

$$P_{\text{SRS}} = \min\{P_{\text{CMAX,c}}, P_0 + \alpha PL_{\text{DL}} + 10\log_{10}(M_{\text{SRS}}) + P_{\text{OFFSET}} + \sigma\}, \tag{1}$$

where the parameters $P_{\text{CMAX,c}}$ is per-carrier maximum power and $P_0$ is the power per resource block. The parameter $\alpha$, which can take a value smaller than or equal to 1, allows path loss compensation. $M_{\text{SRS}}$ is the bandwidth and expressed as a number of resource blocks of the SRS transmission. The explicit power control commands, $P_{\text{OFFSET}}$ and $\sigma$ are included in the uplink scheduling grants [13].
- UE's step 3: Power headroom report is sent by the UE to the BS which indicates how much power the UE is left. The power headroom value is calculated as:

$$P_h = P_{\text{CMAX,c}} - \{P_0 + \alpha PL_{\text{DL}} + 10\log_{10}(M_{\text{SRS}}) + P_{\text{OFFSET}} + \sigma\}, \tag{2}$$

Compared with expression (1), it can be seen that the power headroom is a measure of difference between $P_{\text{CMAX,c}}$ and the actual transmit power.
The power headroom value ($P_h$) is rounded to the closest value in [-23, 40] dB with 1-dB increments, that is power headroom reported value denoted by $PH$ [16]. The negative $P_h$ value implies that the UE was limited by

TABLE III
POWER HEADROOM REPORT MAPPING [16]

| Reported Value | Measured quantity value (dB) |
|---|---|
| $PH$ 00 | -23 $\leq P_h <$ -22 |
| $PH$ 01 | -22 $\leq P_h <$ -21 |
| $PH$ 02 | -21 $\leq P_h <$ -20 |
| $PH$ 03 | -20 $\leq P_h <$ -19 |
| $PH$ 04 | -19 $\leq P_h <$ -18 |
| $PH$ 05 | -18 $\leq P_h <$ -17 |
| ... | ... |
| $PH$ 58 | 35 $\leq P_h <$ 36 |
| $PH$ 59 | 36 $\leq P_h <$ 37 |
| $PH$ 60 | 37 $\leq P_h <$ 38 |
| $PH$ 61 | 38 $\leq P_h <$ 39 |
| $PH$ 62 | 39 $\leq P_h <$ 40 |
| $PH$ 63 | $P_h \geq$ 40 |

$P_{\text{CMAX, c}}$. A total of 64 power headroom reported values require 6-bits signaling (see Table III). The time elapsed from previous power headroom report is more than [10, 20, 50, 100, 200, 1000, inf] transmission time intervals (TTIs).

Based on the above-mentioned processes of UE, the transmissions of SRS and power headroom report are performed. Then BS uses the power headroom report to estimate the path loss and calculate the transmission power of SRS. The BS can obtain the compensated SINR and determine the scheduling metric based on its calculated SINR instead of reported CQI from UE.

- BS's step 1: The BS obtains SRS transmission power by using power headroom report. The estimated power headroom value in dB is calculated by equation (3) that uses an intermediate value in the right column of Table III.

$$\tilde{P}_{\text{h}} = PH - 22.5, \tag{3}$$

The estimated path loss can be expressed by

$$\begin{aligned} PL_{\text{est}} =& \alpha^{-1}\{P_{\text{CMAX,c}} - \tilde{P}_{\text{h}} - P_0 \\ & - 10\log_{10} M_{\text{SRS}} - P_{\text{OFFSET}} - \sigma\}, \end{aligned} \tag{4}$$

$\tilde{P}_{\text{SRSTx}}$ is the transmission power of the SRS estimated at the BS. It can be calculated by the following expression:

$$\begin{cases} P_0 + \alpha PL_{\text{est}} + 10\log_{10} M_{\text{SRS}} & \\ +P_{\text{OFFSET}} + \sigma & if \tilde{P}_{\text{h}} \geq 0 \\ P_{\text{CMAX,c}} & if \tilde{P}_{\text{h}} < 0, \end{cases} \tag{5}$$

All parameters included in the expression (4) and (5) are known at the BS.

- BS's step 2: When the SRS transmitted in whole frequency bands, the BS can calculate the received SINR of each subcarrier.

$$\gamma_{\text{SRS,BS}} = k \cdot \tilde{\gamma}_{\text{SRS}} \qquad , k = \frac{P_{\text{BS,s}}}{\tilde{P}_{\text{SRSTx,s}}}, \tag{6}$$

where $P_{\text{BS,s}}$ is the transmission power per subcarrier of the BS, $\tilde{P}_{\text{SRSTx,s}}$ is the transmission power per subcarrier of the SRS estimated at the BS, and $\tilde{\gamma}_{\text{SRS}}$ is the calculated SINR of the power controlled SRS. The determination of CQI is basically based on the BS transmission power. This step is required to normalize received SINR per subcarrier because the BS and UE have different transmission powers.

- BS's step 3: By the step 2, the BS can calculate the SINR where the power control effect is compensated and we can select a proper CQI per RBG based on its calculated SINR. CQI can be determined by several methods, such as exponential effective SINR mapping (EESM) and mutual information effective SINR mapping (MIESM) [17,18]. These CQIs per RBG are used to calculate scheduling metrics. The resource allocation is performed on a RBG basis, hence downlink scheduling for each UE is usually based on the comparison of per-RBG metric that is a function of its instantaneous data rate.

### B. *Proposed proportional fairness scheduling algorithm*

This section describes how to apply the previously proposed channel estimation method to existing proportional fairness scheduling algorithm. According to the method described in the previous subsection, the BS has individual CQIs that are determined by each RBG. For example, if the system bandwidth is 10MHz, it consists of 17 RBGs and therefore the BS has 17 CQIs. Let $c_k^i(t)$ and $c_{\text{SRS,k}}^i(t)$ denote the CQI for $i^{th}$ user at time $t$ on $k^{th}$RBG reported from UE and determined by SRS, respectively.

The conventional proportional fairness scheduling metric of the $i^{th}$user on $k^{th}$RBG can be expressed as

$$PF_i^k = \arg\max_i\left(\frac{d_k^i(t)}{\overline{R_i(t-1)}}\right) \quad , 1 \leq i \leq N \tag{7}$$

where $d_k^i(t)$ is the instantaneous rate for $i^{th}$user at time $t$ on $k^{th}$RBG, $\overline{R_i(t-1)}$ is the past average throughput up to time slots $t$-1, and $N$ is the number of users [4]. The conventional instantaneous rate can be calculated by:

$$d_k^i(t) = \text{Mod}(c_k^i(t)) \times n \times \text{CodeRate}(c_k^i(t)), \tag{8}$$

where $\text{Mod}(c_k^i(t))$ and $\text{CodeRate}(c_k^i(t))$ are the modulation order and coding rate according to $c_k^i(t)$, respectively. $n$ is the number of resource element on RBG. In conventional proportional fairness method, the instantaneous rate is calculated according to $c_k^i(t)$ reported by each UE. In wideband CQI report, entire RBG corresponds same CQI since a single CQI value is decided for the whole frequency band. However, the proposed scheme utilizes $c_{\text{SRS,k}}^i(t)$ instead of $c_k^i(t)$ feedback from UE. The proposed proportional fairness scheduling metric of the $i^{th}$user on $k^{th}$RBG can be expressed as

$$PF_{\text{SRS},i}^k = \arg\max_i\left(\frac{d_{\text{SRS},k}^i(t)}{\overline{R_i(t-1)}}\right) \quad , 1 \leq i \leq N \tag{9}$$

where $d_{\text{SRS},k}^i(t)$ is the instantaneous rate for $i^{th}$user at time $t$ on $k^{th}$RBG, $\overline{R_i(t-1)}$ is the past average throughput up to time slots $t$-1, and $N$ is the number of users [4]. The proposed instantaneous rate can be calculated by:

$$d^i_{\text{SRS},k}(t) = \text{Mod}(c^i_{\text{SRS,k}}(t)) \times n \times \text{CodeRate}(c^i_{\text{SRS,k}}(t)), \quad (10)$$

where $\text{Mod}(c^i_{\text{SRS,k}}(t))$ and $\text{CodeRate}(c^i_{\text{SRS,k}}(t))$ are the modulation order and coding rate according to $c^i_{\text{SRS,k}}(t)$, respectively. $n$ is the number of resource element on RBG.

## IV. Simulation Results

In this section, we analyze the performance of the proposed algorithm using system level simulation [19,20]. The performance analysis is performed in terms of throughput and fairness index. The simulation parameters are given in Table IV.

TABLE IV
SIMULATION PARAMETER

| Parameter | | Value |
|---|---|---|
| System bandwidth (MHz) | | 10 |
| Number of RBs | | 50 |
| Number of RBs per RBG | | 3 |
| TTI(Transmission Time Interval) (ms) | | 1 |
| Carrier frequency (GHz) | | 2 |
| Velocity (km/h) | | 3 |
| Cell radius (m) | | 200 |
| Number of UEs per cell | | 5 |
| BS antenna gain (dB) | | 5 |
| Power control parameter | $P_{\text{BS}}$ (dB) | 30 |
| | $P_{\text{CMAX,c}}$ (dB) | 23 |
| | $P_0$ (dB) | -72 |
| | $\alpha$ | 0.7 |
| | $M_{\text{SRS}}$ (RB) | 48 |
| | $P_{\text{OFFSET}}$ (dB) | 0 |
| | $\sigma$ (dB) | |

In the simulation, UEs are randomly distributed on a cell and share the radio resources. Radio resources are assigned to the UE by the RBG unit, and both AMC and HARQ are supported in data transmission. If the computed BLER after transmission is higher than the target BLER, then the assigned RBG index, received time, MCS level, and effective SINR are stored in a circular buffer for HARQ, and the data in buffer is retransmitted after HARQ round trip time (RTT). We use the multiplexing HARQ feedback mode and it implies that independent acknowledgement for each transport block is fed back to the BS. This allows independent retransmission for negative acknowledgement (NACK) transport blocks. TDD frame configuration 1, 2, and 6 are used, these downlink/uplink subframe ratio are 6:4, 8:2, and 5:5, respectively. Each UE sends SRS on the whole frequency bands every 10ms. The power headroom report and CQI feedback periods are configured at 100ms and 20ms, respectively.

Fig. 2 shows the normalized system throughput of the proposed algorithm and conventional algorithm. It can be seen that the throughput of the proposed algorithm is higher than that of the conventional algorithm regardless of TDD configuration. In particular, the higher downlink ratio configuration, the greater difference in throughput. The reason is that the proposed method can achieve more accurate channel estimation than the conventional method, and hence the more precise resource allocation is possible.

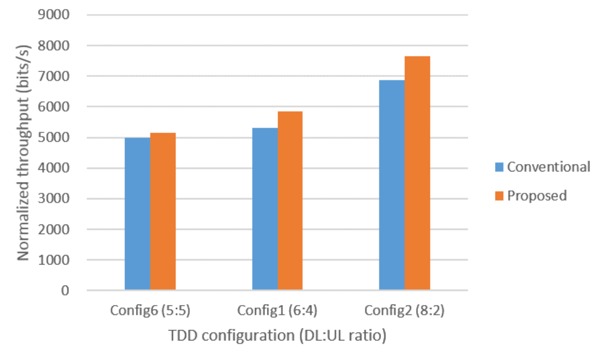


Fig. 2. Normalized system throughput according to downlink scheduling algorithms

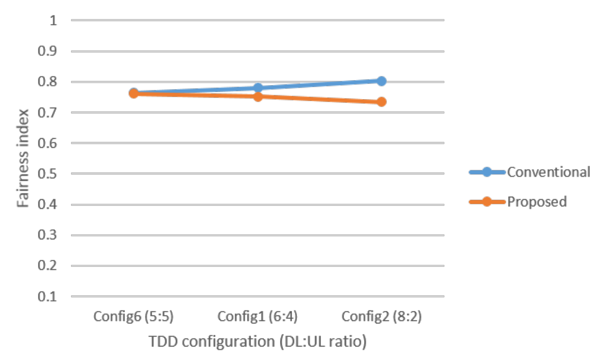


Fig. 3. Fairness index according to downlink scheduling algorithms

The fairness index according to downlink scheduling method is shown in Fig. 3. It is observed that the fairness index experienced by the proposed algorithm is lesser than that of conventional method. This is due to a trade-off between fairness and system throughput. Compared with the CQI reported from UEs that is driven from the average value for channel states of whole RGBs, the proposed algorithm can calculate the PF metric for each RBG and resource allocation is performed based on the comparison of per-RBG PF metrics. These metrics can be interpreted as the transmission priority of each UE on a specific RBG and thus the chances of allocating resources are higher for UE with good channel quality. As a result, the system throughput is improved but the fairness is decreased.

## V. Conclusion

In this paper, we suggested a novel downlink scheduling algorithm using uplink SRS based on the channel reciprocity in LTE-TDD systems since the conventional CQI based scheduling algorithm is insufficient to reflect the channel status of each RBG. In order to exploit the uplink SRS to estimate the absolute downlink channel state, we introduced the power headroom report for path loss estimation of SRS. The metric for downlink scheduling is calculated by using SRS as well as power headroom report. Simulation results indicate that the advised algorithm outperforms the conventional method in system throughput for various TDD configurations. In contrast, the fairness index experienced by the proposed algorithm is lesser than that of conventional method. In conclusion, the considered scheduler with subdivided channel status information over frequency band allocates more resources to the UE with good channel quality, and hence has lower fairness performance. Furthermore, the proposed algorithm outperforms regardless of TDD configuration. So it can be used as an efficient scheduling method in terms of time and frequency when the appropriate TDD configuration is selected based on traffic demands.

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## REFERENCES

[1] E. Lhetkangas, K. Pajukoski, E. Tiirola, G. Berardinelli, I. Harjula, and J. Vihril, "On the TDD subframe structure for beyond 4G radio access network", *Proc. Future Netw. Mobile Summit (FutureNetworkSummit)*, pp. 1-10, 2013

[2] A. Ijaz, L. Zhang, M. Grau, A. Mohamed, S. Vural, A. U. Quddus, M. A. Imran, C. H. Foh, and R. Tafazolli, "Enabling massive IoT in 5G and beyond systems: PHY radio frame design considerations," *IEEE Access*, vol.4, pp. 3322-3339, 24. Jun. 2016.

[3] 3rd Generation Partnership Project; Technical Specification Group Access Network; E-UTRA; Physical channels and modulation, *document 3GPP TS 36.211*, V12.2.0, 2014

[4] 3rd Generation Partnership Project; "Further enhancements to LTE Time Division Duplex (TDD) for Downlink-Uplink (DL-UL) interference management and traffic adaptation," *document 3GPP TR 36.828*, V11.0.0, 2012

[5] Z. Shen, A. Khoryaev, E. Eriksson, and X. Pan, Dynamic uplinkdownlink configuration and interference management in TD-LTE, IEEE Communication Magazine, vol. 50, no. 11, pp. 5159, Nov. 2012.

[6] S. Fouziya Sulthana, and R. Nakkeeran,"Study of downlink scheduling algorithm in LTE networks," *JOURNAL OF NETWORKS*, vol.9, no. 12, pp. 3381-3391, Dec. 2014.

[7] O. Grondalen, A. Zanenlla, K. Mahmood, M. Carpin, J. Rasool, and N. Osterbo, "Scheduling policies in time and frequency domains for LTE downlink channel: a performance comparison," *IEEE Trans. Veh. Technol*, vol.4, pp. 3322-3339, 24. Jun. 2016.

[8] W. Y. Yeo, S. H. Moon, and J. H. Kim, "Uplink Scheduling and Adjacent-Channel Coupling Loss Analysis for TD-LTE Deployment," *The Scientific World Journal*, vol. 2014, Feb. 2014.

[9] H. Holma, and A. Toskala, LTE for UMTS: Evoution to LTE-Advanced, John Wiley and Sons, 2011.

[10] Eril G.Larsson et al., "Massive MIMO for Next Generation Wireless Systems," *IEEE Communications Magazin*, pp. 186-195, Feb. 2014.

[11] S. E. Hajri, M. Assaad, and G. Caire,"Scheduling in Massive MIMO: User Clustering and Pilot Assignment," *IEEE 54th Annual Allerton Conf.*, pp. 107-1114, Feb. 2017.

[12] S. Lagen, A. Agustin, and J. Vidal, "Joint User Scheduling, Precoder Design and Transmit Direction Selection in MIMO TDD Small Cell Networks," *IEEE Trans. on Wireless Commun.*, vol.16, issue. 16, pp. 2434-2449, Apr. 2017.

[13] E. Dahlman, S. Parkvall, and J. Skold, "4G LTE/LTE-Advanced for Mobile Broadband," Evsevier, 2011.

[14] 3rd Generation Partnership Project; Technical Specification Group Access Network; E-UTRA; Physical layer procedure, *document 3GPP TS 36.213*, V12.2.0, 2014

[15] B. Zhou, L. Jiang, and S. Zhao, "Sounding reference signal design for TDD LTE-Advanced system," *IEEE. WCNC*, pp. 410-415, Jun. 2012.

[16] 3rd Generation Partnership Project; Technical Specification Group Access Network; E-UTRA; Requirement for support of radio resource management, *document 3GPP TS 36.133*, V12.5.0, 2014

[17] R. Giuliano, and F. Mazzenga, "Exponential Effective SINR Approximations for OFDM/OFDMA-Based Cellular System Planning," *IEEE Trans. Wireless. Commun*, vol. 8, no. 9, pp. 4434-4439, Sep 2009,

[18] E. Tuomaala and H. Wang, "Effective SINR approach of link to system mapping in OFDM/multi-carrier mobile network," in Proc. *IEEE Int. Conf. Mobile Tech.*, Applic. Sys., Gaungzhou, China, Nov. 2005, 5p.

[19] IEEE 802.16m "Evaluation Methodology Document(EMD)," Jul. 2008.

[20] ITU-R M.2135-1, "Guidelines for evaluation of radio interface technologies for IMT-Advanced," Dec. 2009.