Impact of Multi-User Scheduling on Distributed Antenna Small-Cell Network using STBC Transmit Diversity

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Abstract— **Cooperative distributed antenna transmission (CDAT) in small-cell network significantly improves the spectrum and energy efficiencies simultaneously. In any mobile communications networks, co-channel interference (CCI) from adjacent macro-cells limits the link capacity. A powerful method to effectively utilize the available bandwidth while ensuring the fairness of each user equipment (UE) is a combined use of the single-user space-time block coded transmit diversity (STBC-TD) and the multi-user scheduling. In this paper, we evaluate the link capacity and fairness for three types of the scheduling: proportional fair (PF), the maximum signal-to-noise power ratio (max-SNR), and the round-robin (RR). It is shown that the simple RR scheduling can replace the PF scheduling. Also shown is that by increasing the number of distributed antennas deployed in a macro-cell, the link capacity and the fairness can be improved even in the presence of strong CCI from adjacent macro-cells.**

Keywords—distributed antenna*, *small-cell network*, *scheduling*, *space-time block coding*, *frequency-domain equalization

I. INTRODUCTION

Recently, to provide a good transmission quality over a macro-cell area, we have been studying the single-user space-time block coded transmit diversity (STBC-TD) [1-3] for cooperative distributed antenna transmission (CDAT) [4,5]. The single-user STBC-TD can obtain a large spatial diversity gain since it allows the use of an arbitrary number of distributed antennas. In the mobile communication networks, a large number of user equipments (UEs) are present in a macro-cell and the received signal power and co-channel interference (CCI) power vary according to UE's movement. Therefore, a combined use of the single-user STBC-TD and the multi-user scheduling [6] is needed for effectively utilizing the available bandwidth while ensuring fairness of each UE.

In this paper, we consider the single-user STBC-TD with maximal ratio transmit frequency-domain equalization (MRT-FDE) [7] for the orthogonal frequency division multiplexing (OFDM) [8,9] downlink [10]. By computer simulation, we evaluate the link capacity and the fairness achievable by a combined use of the single-user STBC-TD and multi-user scheduling. Then, we discuss the impact of number of distributed antennas per macro-cell and the impact of distributed antenna deployment strategy (uniform or random) on the link capacity with scheduling (proportional fair (PF), max-SNR, and round-robin (RR)).

The rest of this paper is organized as follows. Sect. II overviews the single-user STBC-TD transmitter/receiver structure for OFDM downlink and presents the link capacity equations. Sect. III introduces the three types of multi-user scheduling (PF, max-SNR, and RR). How the impact of number of distributed antennas per macro-cell and the distributed antenna deployment strategy (uniform or random) affect the link capacity and fairness are discussed in Sect. IV. Sect. V offers some concluding remarks.

Notations: $[.]^*$ and $[.]^H$ represent complex conjugate and Hermitian transpose operations, respectively.

II. SINGLE-USER STBC-TD FOR OFDM DOWNLINK

Figure 1 shows the macro-cell structure in a distributed antenna small-cell network. N_{macro} distributed antennas are deployed over macro-cell area and are connected by optical fiber cables with a macro-cell base station (MBS). In this paper, OFDM downlink is considered. The system bandwidth of N_c-subcarriers is divided into N_{RB} resource blocks, each consisting of M (=N_c/N_{RB}) subcarriers. A total of N_{RB} UEs are given the transmission opportunity by multi-user scheduling (see Sect. III). Each UE is allocated a different resource block. For the single-user STBC-TD, the simple 2×2 Alamouti STBC [1] is adopted and N_{mbs} ($\leq N_{macro}$) distributed transmit antennas and 2 UE receive antennas are assumed.

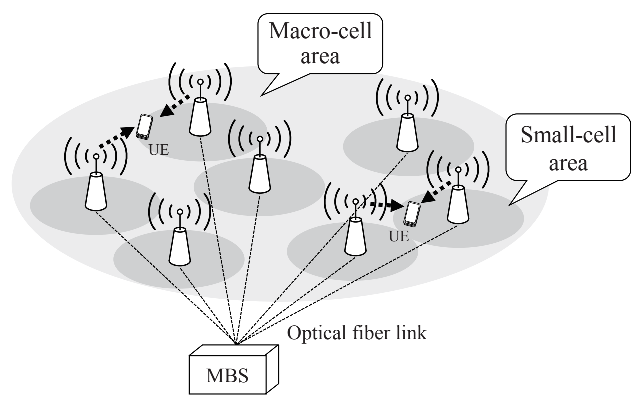


Fig. 1 Macro-cell structure.

A. *STBC-Transmit Diversity*

Figure 2 shows the transmitter/receiver structure of STBC-TD with MRT-FDE. Below, the frequency-domain representation is used assuming that M ($=N_c/N_{RB}$) subcarriers are allocated to each UE.

At the transmitter, 2 consecutive modulated data blocks $\{D_0(k);\ k=0\sim N_c-1\}$ and $\{D_1(k);\ k=0\sim N_c-1\}$ to be transmitted for each UE are encoded by 2×2 Alamouti STBC [1]. The resultant 2 parallel streams of 2 coded signal blocks each can be represented using 2×2 matrix form in the frequency-domain as

$$\mathbf{X}(k)=\begin{bmatrix} D_0(k) & -D_1^*(k) \\ D_1(k) & D_0^*(k) \end{bmatrix}. \tag{1}$$

Then, the frequency-domain transmit signal matrix $\mathbf{S}(k)$ of size $N_{mbs}\times 2$ is generated by multiplying the MRT-FDE weight matrix $\mathbf{W}_{mrt}(k)$ of size $N_{mbs}\times 2$ as

$$\mathbf{S}(k)=\sqrt{\frac{2E_s}{T_s}}\mathbf{W}_{mrt}(k)\mathbf{X}(k), \tag{2}$$

where E_s and T_s denote the transmit data symbol energy and the data symbol period. $\mathbf{W}_{mrt}(k)$ is given as [7]

$$\mathbf{W}_{mrt}(k)=A\mathbf{H}^H(k), \tag{3}$$

where A and $\mathbf{H}(k)$ are respectively, the power normalization coefficient for keeping the average transmit power constant and the frequency-domain propagation channel matrix between N_{mbs} distributed antennas and N_{ue}=2 UE antennas. A and $\mathbf{H}(k)$ are given as

$$A=\left(\frac{1}{M}\sum_{k=0}^{M-1}\sum_{n_{mbs}=0}^{N_{mbs}-1}\sum_{n_{ue}=0}^{N_{ue}-1}\left|H(k;n_{ue},n_{mbs})\right|^2\right)^{-1/2}, \tag{4}$$

$$\mathbf{H}(k)=\begin{bmatrix} H(k;0,0) & \cdots & H(k;0,N_{mbs}-1) \\ \vdots & & \vdots \\ H(k;N_{ue}-1,0) & \cdots & H(k;N_{ue}-1,N_{mbs}-1) \end{bmatrix}, \tag{5}$$

where $H(k;n_{ue},n_{mbs})$ is the (n_{ue},n_{mbs})-th element of $\mathbf{H}(k)$ with $n_{mbs}=0\sim N_{mbs}-1$ and $n_{ue}=0\sim 1$.

The transmit signal corresponding to each UE has M ($=N_c/N_{RB}$) frequency components and consists of 2 time slots. A total of N_{RB} transmit signals are mapped over N_c-subcarriers and transformed into the time-domain transmit signal by N_c-point inverse fast Fourier transform (IFFT). The cyclic prefix (CP) inserted transmit signal is transmitted from N_{mbs} distributed antennas.

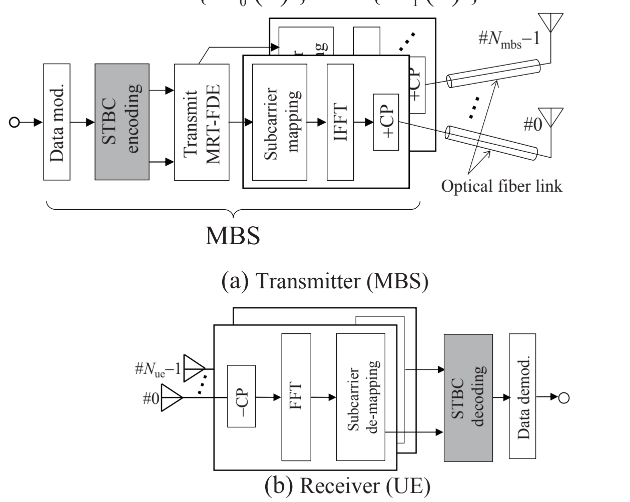
At the receiver, the CP-removed received signal is transformed into the frequency-domain received signal by N_c-point FFT. Then, each UE selects its own M subcarrier components for STBC decoding and maps them to M subcarriers indexed by $k=0\sim M-1$. The frequency-domain received signal of the k-th subcarrier can be expressed in the matrix from as

$$\begin{aligned}\mathbf{R}(k)&=\mathbf{H}(k)\mathbf{S}(k)+\mathbf{N}(k)\\ &=\sqrt{\left(\frac{2E_s}{T_s}\right)}A\left(\mathbf{H}(k)\mathbf{H}^H(k)\right)\mathbf{X}(k)+\mathbf{N}(k)\end{aligned}, \tag{6}$$

where $\mathbf{N}(k)=\{N(k;n_{ue},q);\ n_{ue}=0\sim 1,\ q=0\sim 1\}$ is a 2×2 equivalent noise (noise plus CCI) matrix. Each element of $\mathbf{N}(k)$ is independent zero-mean complex Gaussian variable with variance $2(N_0+I_{0,u})/T_s$, where N_0 and $I_{0,u}$ are respectively the one-sided noise power spectrum density and the CCI power spectrum density of the u-th UE. The 2×2 Alamouti STBC decoding is applied to obtain the frequency-domain received signals, $\{\hat{D}_0(k)\}$ and $\{\hat{D}_1(k)\}$, as [7]

$$\begin{bmatrix}\hat{D}_0(k)\\ \hat{D}_1(k)\end{bmatrix}=\begin{bmatrix}R_{0,0}(k)+R_{1,1}^*(k)\\ R_{0,1}(k)-R_{1,0}^*(k)\end{bmatrix}, \tag{7}$$

where $R_{n_{ue},q}(k)$ is the (n_{ue},q)-th element of $\mathbf{R}(k)$. Finally, data demodulation on $\{\hat{D}_0(k)\}$ and $\{\hat{D}_1(k)\}$ is carried out.



(a) Transmitter (MBS)

(b) Receiver (UE)

Fig. 2 OFDM downlink transmitter/receiver structure.

B. *Link Capacity*

The OFDM downlink capacity $C_u(n)$ (bps/Hz) of the n-th resource block for the given u-th UE location is computed using Shannon capacity formula [8] as

$$C_u(n)=\frac{1}{M}\sum_{k=0}^{M-1}\log_2\left(1+\gamma_u(k)\right), \tag{8}$$

where $\gamma_u(k)$ is the instantaneous received signal-to-interference plus noise power ratio (SINR) after STBC decoding and is expressed as

$$\gamma_u(k)=\frac{\dfrac{E_s}{N_0}\left|\hat{H}(k)\right|^2}{\mu_u^{noise+CCI}}, \tag{9}$$

where E_s/N_0 is normalized transmit symbol energy and thermal noise power spectral density ratio. $\hat{H}(k)$ and $\mu_u^{noise+CCI}$ are respectively, the downlink equivalent channel gain after STBC decoding and the downlink noise plus CCI to noise power spectrum density ratio. They are given as

$$\hat{H}(k)=\frac{\sum_{n_{ue}=0}^{N_{ue}-1}\sum_{n_{mbs}=0}^{N_{mbs}-1}\left|H(k;n_{ue},n_{mbs})\right|^2}{\sqrt{\frac{1}{M}\sum_{k=0}^{M-1}\sum_{n_{mbs}=0}^{N_{mbs}-1}\sum_{n_{ue}=0}^{N_{ue}-1}\left|H(k;n_{ue},n_{mbs})\right|^2}}, \quad (10)$$

$$\mu_u^{noise+CCI}=1+\frac{I_{0,u}}{N_0}. \quad (11)$$

III. MULTI-USER SCHEDULING

In this paper, we consider three types of scheduling (PF, max-SNR, and RR) [6] and assuming the scheduler selects N_{RB} UEs from U_{act} active UEs.

A. *PF scheduling*

The PF scheduler is introduced to make a fair tradeoff between system link capacity and user fairness. The user $u^*(n,t)$, which is allocated the n-th resource block with n=0~$N_{RB}-1$ at the t-th time slot, is expressed as

$$u^*(n,t)=\arg\max_{0\le u\le U_{act}-1}\frac{\hat{C}_u(n,t)}{\overline{C}_u(t-1)}, \quad (12)$$

where $\hat{C}_u(n,t)$ is the UE link capacity estimate if the u-th UE is allocated the n-th resource block at the t-th time slot. $\overline{C}_u(t-1)$ is the average UE link capacity for the u-th UE until (t−1)-th time slot and is updated by

$$\overline{C}_u(t)=\begin{cases}\left(1-\frac{1}{T_{PF}}\right)\overline{C}_u(t-1) & u\ne u^*\\ \left(1-\frac{1}{T_{PF}}\right)\overline{C}_u(t-1)+\frac{1}{T_{PF}}C_u(t) & u=u^*\end{cases}, \quad (13)$$

where T_{PF} and $C_u(t)$ are respectively, the moving average interval and the UE link capacity of the u-th UE at the t-th time slot.

Since the information of co-channel interference from adjacent macro-cells is not available before starting user data transmission, the UE link capacity estimate $\hat{C}_u(n,t)$ is computed using the received SNR as

$$\hat{C}_u(n,t)=\frac{1}{M}\sum_{k=0}^{M-1}\log_2\left(1+\frac{E_s}{N_0}\left|\hat{H}(k)\right|^2\right). \quad (14)$$

B. *Max-SNR scheduling*

The Max-SNR scheduler allocates the transmission opportunity to an UE with the best channel condition every time slot. The user $u^*(n,t)$ is expressed as

$$u^*(n,t)=\arg\max_{0\le u\le U_{act}-1}\hat{C}_u(n,t). \quad (15)$$

C. *RR scheduling*

The RR scheduler allocates the transmission opportunity to all UEs in turn without considering channel condition and all UEs get equal transmission opportunity, however, some resource block may be allocated to a particular UE with bad channel condition. Thus, the link capacity of each UE is not fair in most cases.

However, under the broadband frequency-selective fading environment with the large spatial diversity gain obtained by STBC-TD, the difference of equivalent channel gains among N_{RB} resource blocks is substantially reduced for almost all active UEs. Therefore, the RR scheduling is expected to achieve the same link capacity and fairness as the PF scheduling.

IV. COMPUTER SIMULATION

Computer simulation conditions are summarized in Table 1. We consider a cellular model shown in Fig. 3. The macro-cell of interest is surrounded by 6 co-channel macro-cells. In the small-cell network, N_{macro} distributed antennas are deployed over each macro-cell, either uniformly (shown in Fig. 3) or randomly. R and R' denote macro-cell radius and small-cell radius, respectively. The broadband wireless propagation is characterized by distance-dependent path loss, log-normally distributed shadowing loss and L-path frequency-selective fading [8]. The channel between a particular UE and DA is modeled as either Nakagami-Rice fading or Rayleigh fading, depending on the distance between receive antenna of UE and transmit DA. We assume ideal channel estimation.

We evaluate the relationship between the link capacity (the average sum link capacity or the UE link capacity) and the average FI. The 5% outage UE link capacity is considered, which represents the 5th percentile of the UE link capacity distribution.

Table 1. Computer simulation conditions.

Network	No. of distributed antennas	N_{macro}=7, 19, 37
	Small-cell radius	$R'=R/\sqrt{N_{macro}}$
Transmitter/ Receiver	Normalized transmit E_s/N_0	E_s/N_0=0dB
	No. of FFT/IFFT block size	N_c=1024
	Guard interval length	N_g=16
	No. of transmit antennas	N_{mbs}=4
	No. of receive antennas	N_{ue}=2
Propagation channel	Path loss exponent	α=3.5
	Shadowing loss standard deviation	σ=7.0dB
	Channel estimation	Ideal
	Frequency-Selective block Nakagami-Rice and Rayleigh fading	
	K factor of Nakagami-Rice	K=10dB
	Power delay profile (PDP) shape	16-path uniform

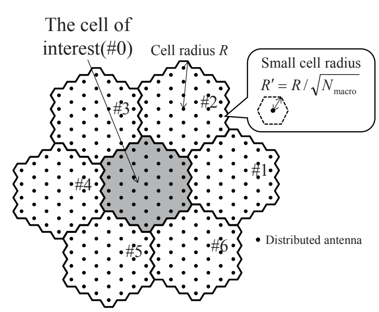


Fig. 3 Small-cell network using uniform DA deployment (N_{macro}=37).

A. *Propagation channel model and fairness definition*

The distance between the n_{ue}-th receive antenna of UE in the c-th macro-cell and the n_{mbs}-th transmit DA in the c'-th macro-cell is denoted by $d(n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))$. It is assumed that the channel is Nakagami-Rice fading (K>0) if $d(n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))$ is equal to or shorter than $R/\sqrt{N_{\mathrm{macro}}}$, otherwise the channel is Rayleigh fading (K=0), where K is defined as the direct-to-sum of delay paths power ratio.

The channel impulse response $h(\tau; n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))$ between the n_{ue}-th receive antenna of UE in the c-th macro-cell and the n_{mbs}-th transmit DA in the c'-th macro-cell can be expressed as

$$\begin{aligned} &h(\tau; n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c')) \\ &= \sqrt{d_{u(c),n_{\mathrm{mbs}}(c')}^{-\alpha} \cdot 10^{-\frac{\eta_{u(c),n_{\mathrm{mbs}}(c')}}{10}}} \\ &\times \left\{ \begin{array}{l} \sqrt{\dfrac{K}{K+1}} \exp\left(j\theta(n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))\right) \delta\left(\tau - \tau(n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))\right) \\ + \sqrt{\dfrac{1}{K+1}} \sum_{l=0}^{L-1} \zeta(l; n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c')) \delta\left(\tilde{\tau}(l; n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))\right) \end{array} \right\} \end{aligned} \quad ,(16)$$

where α is the path loss exponent and $\eta_{u(c),n_{\mathrm{mbs}}(c')}$ is the shadowing loss in dB having zero-mean and standard deviation σ. $\theta(n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))$ is the phase of direct path which is assumed to be uniformly distributed and $\tau(n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))$ is the delay time of direct path. $\zeta(l; n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))$ and $\tilde{\tau}(l; n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))$ are the complex-valued path gain following the zero-mean Gaussian distribution and the l-th path delay time, respectively. The frequency-domain channel transfer function in (5) is obtained by applying DFT to $h(\tau; n_{\mathrm{ue}}(c), n_{\mathrm{mbs}}(c'))$. Fairness index (FI) is defined by [11].

$$\mathrm{FI} = \frac{\left(\sum_{u=0}^{U_{\mathrm{act}}-1} \frac{1}{T_{\mathrm{ave}}} \sum_{t=0}^{T_{\mathrm{ave}}-1} C_u(t) \right)^2}{U_{\mathrm{act}} \cdot \sum_{u=0}^{U_{\mathrm{act}}-1} \left| \frac{1}{T_{\mathrm{ave}}} \sum_{t=0}^{T_{\mathrm{ave}}-1} C_u(t) \right|^2}, \quad (17)$$

where T_{ave} (>>T_{PF}) is the moving average interval. FI approaches 1 when the difference in the average link capacity among UEs becomes small. On the other hand, FI reduces and approaches $1/U_{\mathrm{act}}$ when the difference in the average link capacity among UEs becomes large.

B. *Link capacity and fairness*

Figure 4 shows the relationship between the average sum link capacity and the average FI of each scheduling scheme. Figure 5 shows the relationship between the 5% outage UE link capacity and the average FI. It can be seen that the difference in both the sum link capacity and the average FI between the RR and the PF scheduling is marginal under both single-cell (without the CCI) and multi-cell (with the CCI) environments. The possible reason is discussed below. In the broadband wireless communication, the channel frequency selectivity becomes stronger. Furthermore, the large spatial diversity gain is obtained by STBC-TD. Consequently, the difference in the averaged channel gains due to fading among active UEs is reduced and hence the PF scheduling cannot fully obtain multi-user diversity gain.

To confirm that the difference of equivalent channel gains among UEs is marginal, the distribution of averaged channel gain (i.e., channel gains averaged over M subcarriers) of a resource block is provided in Fig. 6. It can be seen from Fig. 6 that the larger the number of subcarriers per resource block, the smaller the variance of average channel gain. This suggests that the multi-user diversity gain decreases as the resource block size becomes broader, and the RR scheduling can replace the PF scheduling as shown in Figs. 4 and 5. In addition, we assume a resource block containing 512 subcarriers per UE in this paper as it is expected that much broader band resource block than the current 4G will be used in 5G systems.

It can be seen from Fig. 5 that the 5% outage UE link capacity of the max-SNR scheduling is very low. This is because the max-SNR scheduling always selects an UE with best channel condition and neglects other UEs under worse channel condition.

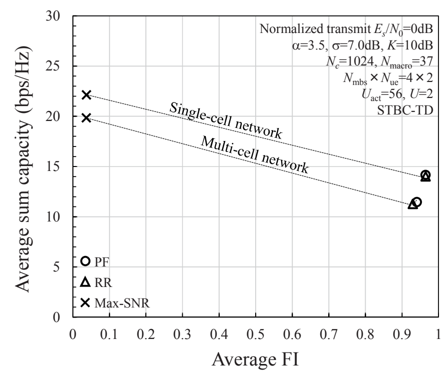


Fig. 4 Average sum link capacity and average FI (N_{macro}=37, single-cell vs multi-cell).

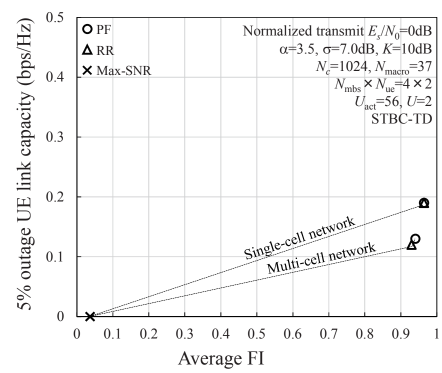


Fig. 5 5% outage UE link capacity and average FI (N_{macro}=37, single-cell vs multi-cell).

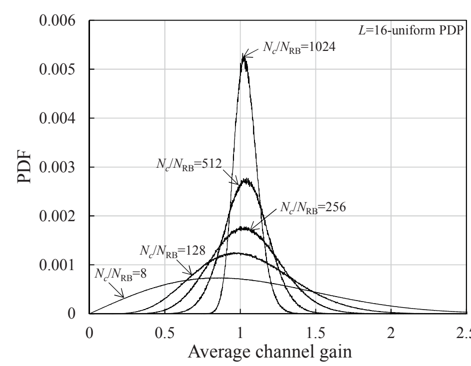


Fig. 6 Distribution of average channel gain.

C. *Impact of the number of distributed antennas*

The relationship between the average link capacity and the average FI and that of between the 5% outage UE link capacity and the average FI when N_{macro} is varied from 7 to 37 are shown in Figs. 7 and 8, respectively. For comparison, the results using the random distributed antenna deployment strategy are also plotted.

It can be seen from Fig. 7 that both the sum link capacity and the FI are improved by increasing N_{macro}. Furthermore, the difference in both the sum link capacity and the average FI between the RR scheduling and the PF scheduling decreases as N_{macro} increases (when N_{macro}=7→37, the difference in the FI reduces from 2.3 to 1.2%, the difference in the sum link capacities reduces from 4.0％ to 1.6％). This is because increasing N_{macro} leads to higher probability that DAs closer to an active UE can be found. Hence, the negative impacts of path loss and shadowing loss are further mitigated, thereby improving the link capacity and fairness for cell-edge UEs. Furthermore, it can be seen from Figs. 7 and 8 that the achievable link capacity and FI are almost insensitive to the strategy of distributed antenna deployment.

V. CONCLUSIONS

In this paper, we considered a combined use of the single-user STBC-TD with MRT-FDE and the multi-user scheduling for the OFDM downlink transmission and evaluated by the computer simulation the link capacity and the fairness. We showed that for broadband transmissions, the simple RR scheduling can replace the PF scheduling and that increasing the number of distributed antennas per macro-cell is quite effective to improve both the link capacity and the fairness.

In this paper, we assumed the perfect channel estimation. The impact of the imperfect channel estimation on the link capacity and the fairness is left as our future study.

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REFERENCES

[1] S.M. Alamouti, "A simple transmit diversity technique for wireless communications," IEEE J. Sel. Areas. Commun., vol.16, no.8, pp.1451-1458, Oct. 1998.

[2] V. Tarokh, H. Jafarkhani and A. R. Calderbank, "Space-time block codes from orthogonal designs," IEEE Trans.on Inform. Theory, Vol. 45, No. 5, pp. 1456-1467, July 1999.

[3] K. Takeda, T. Itagaki, and F. Adachi, "Application of space-time transmit diversity to single-carrier transmission with frequency-domain equalization and receive antenna diversity in a frequency-selective fading channel," IEE Proc.-Commun., vol. 151, No.6, pp. 627-632, Dec. 2004.

[4] F. Adachi, K. Takeda, T. Obara, T. Yamamoto, and H. Matsuda, "Recent advances in single-carrier frequency-domain equalization and distributed antenna network," IEICE Trans. Fundamentals, Vol. E93-A, No. 11, pp. 2201-2211, Nov. 2010.

[5] F. Adachi, A. boonkajay, Y. Seki, T. Saito, S. Kumagai and H. Miyazaki, "Cooperative Distirbuted Antenna Transmission for 5G Mobile Communications Network," to be published in IEICE Trans. Commun., Vol. 100-E, No. 8, Aug. 2017.

[6] E. Dahlman, S. Parkvall, and J. Sköld, *4G:LTE/LTE-Advanced for Mobile Broadband*, *2nd ed*., Academic Press, 2014.

[7] H. Tomeba, K. Takeda, and F. Adachi, "Space-Time Block Coded Joint Transmit/Receive Diveristy in a Frequency-Nonselective Rayleigh Fading Channel," IEICE Trans. Commun., Vol.E89-B, No.8, pp.2189-2195, Aug. 2006.

[8] J. G. Proakis and M. Salehi, *Digital communications*, 5th ed., McGraw-Hill, 2008.

[9] R. Prasad, *OFDM for Wireless Communication Systems*, Artech House, 2004.

[10] H. Miyazaki and F. Adachi, "Distributed antenna selection for OFDM space-time block coded diversity," to be presented at 2016 IEEE 84th Veh. Technol. Conf. (VTC2016-Fall), Montréal, Canada, 18-21 Sept. 2016.

[11] R. Jain, D. Chiu, and W. Hawe, "A Quantitative Measure of Fairness nad Discrimination for Resource Allocation in Shared Computer System," DEC Research Report, TR-301, Sept. 1984.

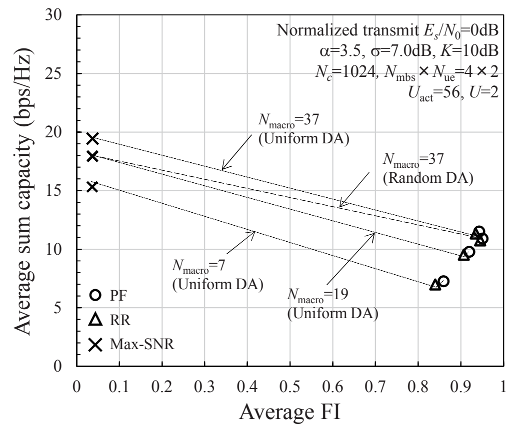

Fig. 7 Average sum link capacity and average FI (N_{macro}=7,19,37).

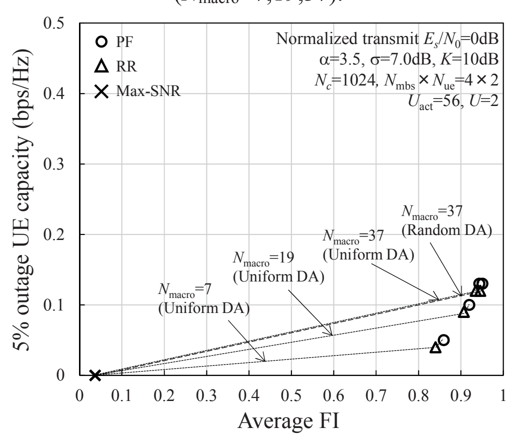

Fig. 8 5% outage UE link capacity and average FI (N_{macro}=7,19,37).