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A study of power allocation in multi-MRN aided multiuser networks

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Abstract It is promising that mobile relay nodes (MRNs), i.e., relays mounted on top of transportation vehicles, are deployed in future mobile communication systems in order to improve system performance. In this paper a multi-MRN aided multiuser system is studied. The system performance under direct transmission mode and MRN assisted transmission mode are compared with variable parameter of vehicle penetration loss (VPL). The mobile users are separated into two categories in which the direct transmission mode and the MRN assisted transmission mode are selected to transmit in downlink, respectively. A novel power allocation algorithm is proposed to increase the average system capacity under the constraint of total transmit power. The different power allocation schemes are applied for users in two categories to improve the system performance. It is demonstrated by simulation results that the proposed algorithm outperforms the average power allocation algorithm.

Keywords mobile relay nodes (MRN), vehicle penetration loss (VPL), transmission mode, average system capacity, power allocation

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1 Introduction

In conventional cellular mobile systems a base station (BS) used to communicate with many terminal users within its coverage cell by radio signal directly. High transmit power is required for users located in cell-edge area to communicate directly with the relevant BS, therefore, the severe interference is introduced to neighbor cells [1]. One approach to solve this problem is the relay technology. Relay is one of the primary innovations of long-term evolution-advanced (LTE-A) standardization, which is considered as an effective method to increase the cell coverage radius and system throughput. The mobile relay node (MRN) is considered as an enhanced version of fixed relay node to be deployed in the transportation vehicles, such as the bus, car, and train. Mobile relay nodes are expected to improve the quality of service (QoS) for passengers on high speed vehicles whose voice and data communication encounter severe wireless channel fading, high call drop rate, quite serious signaling congestion and excessive power consumption [1].

MRN combined with Doppler diversity is investigated [2] to improve reliability in high speed railway scenario. The potential capacity and coverage improvement with deploying coordinated and cooperative

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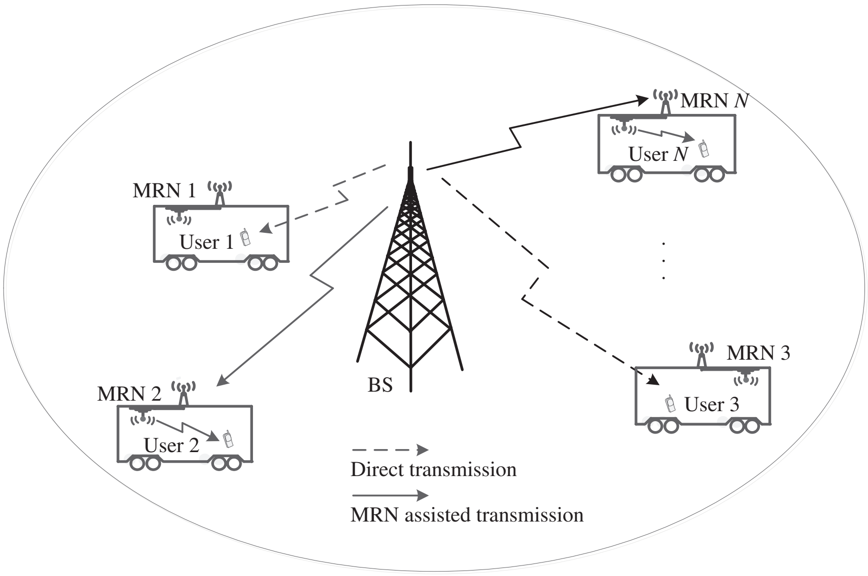

Figure 1 Framework of the multi-MRN aided multiuser system.

relay nodes on top of trains have been shown in [3–5]. A cross-layer design jointly incorporating relay nodes selection and power allocation to increase the network lifetime is proposed in [6]. Through minimizing the asymptotic outage probability, an optimal power allocation scheme is developed in a multiuser relay network [7]. However, the aforementioned works did not elaborate the parameter of vehicle penetration loss (VPL) that might be as high as 25 dB for the user terminal inside a mini-van at the carrier frequency of 2.4 GHz [8]. It is inevitable that the higher VPL will be introduced in higher carrier frequencies allocated to next generation mobile systems. The deployment of MRNs on top of public transportation vehicles is very favorable since the effect of VPL is eliminated [7]. It is obtained by taking advantage of separate indoor and outdoor antenna elements that are connected through a coaxial cable introducing negligible transmission loss. In [9], the system performance of the direct transmission (DT) and the MRN assisted transmission (MRNaT) under various parameters of VPL is investigated in the system including only one MRN and one user terminal.

In this paper, a multi-MRN aided multiuser system is investigated. A novel power allocation algorithm is proposed to improve the average system capacity in downlink under the constraint of total transmit power at BS. According to the proposed algorithm, users are firstly separated into two categories based on their respective transmission mode being selected. Secondly, the water-filling power allocation (WFPA) [10–12] is applied for users employing the direct transmission while the average power allocation (APA) is applied for users employing the MRN assisted transmission. It is demonstrated through the simulation results that the average system capacity achieved by the proposed algorithm is higher than that by any single transmission mode with average power allocation.

2 System framework

A cellular system comprising multiple MRN aided mobile users as shown in Figure 1 is studied in this paper. The BS is located in the center of a cell whose radius is R. It is assumed that each MRN serves only one passenger inside the vehicle without loss of generality. The total number of MRNs or terminal users are assumed as N. In downlink the radio signal are transmitted from the BS to users through two transmission modes, i.e., the direct transmission mode and the MRN assisted transmission mode. Following the glossary in 3GPP standards, the link between BS and MRN is defined as the backhaul link while the link between MRN and user terminal is the access link [7]. The backhaul link operates in the same carrier frequency as the access link. The time division multiplexing (TDM) mode is employed for the MRN assisted transmission. Each transmission slot is divided into two consecutive time sub-slots

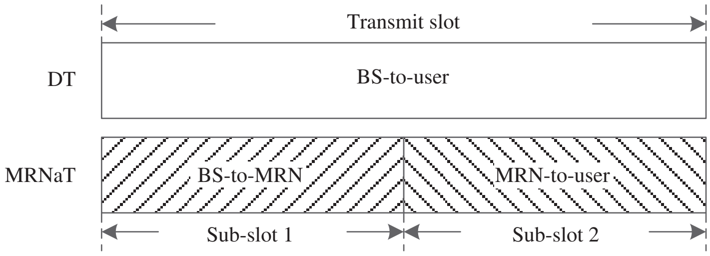

Figure 2 The transmit timing structure of two transmission modes.

with same length. The transmit slot timing structure of two transmission modes is illustrated in Figure 2. By the direct transmission mode radio signal is propagated directly from the BS to the user terminal with penetrating the vehicle shell. By contrast, under the MRN assisted transmission mode, the BS transmits radio signal to MRN outdoor antenna element mounted outside the vehicle in sub-slot 1, then the MRN re-transmits to user terminal in sub-slot 2 by its indoor antenna element mounted inside the vehicle. It is assumed both indoor and outdoor antenna element are separately deployed on an MRN equipment. In this paper the decoded-and-forward (DF) scheme is used in downlink at each MRN since it enables users to exploit full spatial diversity [6, 13]. Because the parameter of VPL is assumed as high as 25 dB in this paper, for the MRN assisted transmission mode the combing of signal received in sub-slot 1 and sub-slot 2 is not considered at user terminal. Similarly, during transmission in the second sub-slot the interference from other MRNs to the receiving user terminal inside vehicle carriage is ignored because the radio signal transmitted from indoor antenna elements of interference MRNs are attenuated with double VPL due to propagation penetrating across two shells of two individual vehicles concerned.

2.1 Direct transmission mode

Through the direct transmission, the received signal of the kth ($k = 1, 2, \ldots, N$) user is expressed as

$$y_{su_k} = h_{su_k}\sqrt{p_k}x_{su_k} + n_{u_k}, \tag{1}$$

where h_{su_k} is the wireless channel coefficient between the BS and the kth user terminal. p_k represents the transmit power for the kth user allocated by the BS and x_{su_k} is transmit data symbol with unit variance. $n_{u_k} \sim \mathcal{NC}(0, \sigma^2)$ stands for the additive white Gaussian noise (AWGN) with zero mean and variance of σ^2. Therefore, the achievable link capacity of the kth user through the direct transmission can be expressed as

$$C_{\mathrm{dt}\_su_k} = \log_2\left(1 + \frac{|h_{su_k}|^2 p_k}{\sigma^2}\right). \tag{2}$$

2.2 MRN assisted transmission mode

Under the MRN assisted transmission mode, the BS transmits data symbol x_{su_k} to the MRN corresponding to the kth user during the first time sub-slot. The signal received by the MRN in sub-slot 1 is

$$y_{sr_k} = h_{sr_k}\sqrt{p_k}x_{su_k} + n_{r_k}, \tag{3}$$

where h_{sr_k} is the wireless channel coefficient over the backhaul link. It is assumed that the channel coefficient remains unchanged during two time sub-slots within one transmit slot. n_{r_k} stands for the AWGN at the MRN corresponding to the kth user.

During the second time sub-slot, the corresponding MRN transmits regenerated data symbol x_{ru_k} to the kth user terminal. The signal received by the kth user in sub-slot 2 is

$$y_{ru_k} = h_{ru_k}\mu_r x_{ru_k} + n_{u_k}, \tag{4}$$

where h_{ru_k} is the channel coefficient over the access link and μ_r is an transmit power amplification factor of the MRN to ensure that the power constraints are satisfied. In addition, the retransmitted signal of data symbol of the MRN x_{ru_k} depends on y_{sr_k}. It is assumed that the decode-and-forward scheme is utilized at each MRN and MRNs are able to correctly decode the original data symbols via backhaul link and retransmit to the users via access link. Furthermore, $\mu_r = \sqrt{p_r}$ and $x_{ru_k} = x_{su_k}$ are assumed and substituted into (4), where p_r denotes the transmit power of the MRN. Thus Eq. (4) is further deduced as

$$y_{ru_k} = h_{ru_k}\sqrt{p_r}x_{su_k} + n_{u_k}. \tag{5}$$

Therefore, the achievable link capacity of the kth user through MRN assisted transmission is

$$C_{\mathrm{MRN\_}su_k} = \frac{1}{2}\min\left\{\log_2\left(1+\frac{|h_{sr_k}|^2 p_k}{\sigma^2}\right), \log_2\left(1+\frac{|h_{ru_k}|^2 p_r}{\sigma^2}\right)\right\}. \tag{6}$$

The first term in (6) represents the capacity of the backhaul link and the second term in (6) represents the capacity of the access link. The factor of 1/2 is due to the time division multiplexing that two time sub-slots are occupied under the MRN assisted transmission mode [13].

Because the radio propagation channel inside the public transportation vehicles are similar, the transmit power of each MRN is assumed to be the same as p_r in this paper. It is noted that this paper focus on downlink transmit power allocation at the BS and the resource allocation of MRNs in the second time sub-slot through MRN assisted transmission is not addressed. Moreover, the total transmit power of BS in practice is much higher than that of MRN equipment. It is implied that the transmit power allocation at the BS to multiple MRNs which are randomly distributed within a cell is the dominant factor to improve the average system capacity in downlink.

2.3 Channel model

The wireless channel coefficients are modeled as follows,

$$h_{su_k} = \Gamma_{su_k}\sqrt{\beta d_{su_k}^{-\alpha}\gamma_{su_k}(1-\varepsilon)}, \tag{7}$$

$$h_{sr_k} = \Gamma_{sr_k}\sqrt{\beta d_{sr_k}^{-\alpha}\gamma_{sr_k}}, \tag{8}$$

$$h_{ru_k} = \sqrt{\kappa}, \tag{9}$$

where Γ_{su_k} and Γ_{sr_k} are the complex Gaussian coefficient representing Rayleigh small-scale fading with $\Gamma \sim \mathcal{NC}(0,1)$. The wireless channel model for urban non-line-of-sight (NLOS) microcell scenario [14] is assumed as the exponential path loss model. α is the path-loss exponent and β is the path-loss constant. d_{su_k} is the distance between the BS and the kth user terminal while d_{sr_k} is the distance between the BS and the kth MRN. It is noted that d_{su_k} and d_{sr_k} are assumed being equal in this paper. γ_{su_k} and γ_{sr_k} are log-normal shadow fading coefficients with zero mean and standard deviation of 8 dB [15]. Moreover, ε denotes VPL parameter with $0 < \varepsilon \leqslant 1$. Since the distance between the user terminal and indoor antenna element of MRN is usually less than 5 meters and there is existing mostly a line-of-sight (LOS) link [7] inside vehicle carriage, the path loss of the access link is assumed as a constant parameter κ. The value of κ is assumed to be 0.99 without loss of generality.

3 Transmission mode selection

As described above, two transmission modes, i.e., the direct transmission mode and the MRN assisted transmission mode, are selected and utilized at BS to transmit in downlink to distinct terminal users distributed within the cell.

3.1 System capacity by direct transmission

When the BS transmits radio signal to all N user terminals inside vehicles by direct transmission, the downlink average system capacity is expressed as

$$\overline{C_{\mathrm{dt}}} = \frac{1}{N}\sum_{k=1}^{N} C_{\mathrm{dt\_}su_k}. \tag{10}$$

By substituting (2) and (7) into (10), $\overline{C_{\mathrm{dt}}}$ is expressed as a function of parameter of VPL as follows,

$$\overline{C_{\mathrm{dt}}} = \frac{1}{N}\sum_{k=1}^{N}\log_2\left[1+\frac{\Gamma_{su_k}^2\beta d_{su_k}^{-\alpha}\gamma_{su_k}p_k}{\sigma^2}(1-\varepsilon)\right]. \tag{11}$$

From (11) it is clarified that the downlink average system capacity through direct transmission decreases monotonously when the parameter of VPL increases.

3.2 System capacity by MRN assisted transmission

When the BS transmits radio signal to all N user terminals inside vehicles by MRN assisted transmission, the downlink average system capacity is expressed as

$$\overline{C_{\mathrm{MRN}}} = \frac{1}{N}\sum_{k=1}^{N}C_{\mathrm{MRN}\_su_k}. \tag{12}$$

By substituting (6), (8) and (9) into (12), the detailed expression of $\overline{C_{\mathrm{MRN}}}$ is derived as

$$\overline{C_{\mathrm{MRN}}} = \frac{1}{2N}\sum_{k=1}^{N}\min\left\{\log_2\left(1+\frac{\beta d_{sr_k}^{-\alpha}\gamma_{sr_k}|\Gamma_{sr_k}|^2p_k}{\sigma^2}\right),\log_2\left(1+\frac{\kappa p_r}{\sigma^2}\right)\right\}. \tag{13}$$

3.3 System capacity with transmission mode selection

It is heuristic that the MRN assisted transmission is not equally beneficial to all users at different locations distributed within the cell. In other words, the users apart farther away from the BS most likely benefit from the MRN assisted transmission much more than those nearby the BS due to VPL [16]. For the user nearby the BS, the superior link capacity might be obtained through the direct transmission than the MRN assisted transmission. Therefore, it is not properly that the MRN assisted transmission is employed for all users in the cell to communicate with BS. Because of the DF relay strategy based on TDM scheme [17], it is heuristic to explore the trade-off in link capacity that are provided by two transmission modes through comparing the expression (2) and (6) under the same constraint of total transmit power. As for multiple MRN aided users system scenario, an intuitive solution to maximize the average system capacity is that a specific transmission mode is determined for each user by the BS. Firstly the BS gathers channel quality information (CQI) including the channel coefficients of the direct transmission links, backhaul links, and access links corresponding to all users [16, 18]. Secondly, the link capacity based on the direct transmission mode and MRN assisted transmission mode are calculated by the BS for each individual user terminal. Finally, one specific transmission mode that provides higher link capacity is selected for each user by the BS respectively.

It is assumed that U_{dt} denotes the set of users for which the direct transmission mode is selected while U_{MRN} denotes the set of users for which the MRN assisted transmission mode is selected. If the achievable link capacity of the kth user terminal through the direct transmission is higher than that through MRN assisted transmission, the kth user is collected into the set U_{dt}, otherwise the kth user is collected into the set U_{MRN}. It is defined as

$$U_{\mathrm{dt}} = \{u_k|C_{\mathrm{dt}\_su_k} > C_{\mathrm{MRN}\_su_k}\}, \tag{14}$$

$$U_{\mathrm{MRN}} = \{u_k|C_{\mathrm{dt}\_su_k} \leqslant C_{\mathrm{MRN}\_su_k}\}. \tag{15}$$

Without loss of generality, it is assumed that $\dim\{U_{\mathrm{dt}}\} = N_1$ and $\dim\{U_{\mathrm{MRN}}\} = N_2$, $\dim\{\cdot\}$ denotes the dimension of a set. It is obvious that $N_1 + N_2 = N$.

The total system capacity equals the sum of link capacity of all users in the set of U_{dt} and U_{MRN}. Therefore, the average system capacity can be derived as follows,

$$\overline{C} = \frac{1}{N}\left(\sum_{i=1}^{N_1}C_{\mathrm{dt}\_su_i} + \sum_{j=1}^{N_2}C_{\mathrm{MRN}\_su_j}\right). \tag{16}$$

4 Transmit power allocation algorithm

For the sake of simplicity, the average power allocation is often utilized for all users in multiuser networks. In this section, a novel transmit power allocation algorithm based on transmission mode selection as discussed in Section 3 is proposed. According to the proposed algorithm, named as the mixed power allocation (MPA), the water-filling power allocation [19, 20] is applied for users in the set of U_{dt} while the average power allocation is applied for users in the set of U_{MRN}. The total transmit power of BS is represented as P_s. Thus the sum of transmit power for all N users is constrained as

$$\sum_{i=1}^{N_1} p_i + \sum_{j=1}^{N_2} p_j \leqslant P_s. \tag{17}$$

4.1 Average power allocation for users in U_{MRN}

It is assumed that transmit power is allocated equally to users in the set of U_{MRN} and the transmit power of the jth user ($j = 1, 2, \ldots, N_2$) is deduced as

$$p_j = \frac{P_s}{N}, \tag{18}$$

corresponding to the jth user in U_{MRN} with MRN assisted transmission.

4.2 Water-filling power allocation for users in U_{dt}

By substituting $\sum_{j=1}^{N_2} p_j = \frac{N_2}{N} P_s$ into (17), the total transmit power of users in U_{dt} is constrained by

$$\sum_{i=1}^{N_1} p_i \leqslant \frac{N_1}{N} P_s. \tag{19}$$

The link capacity corresponding to ith user with direct transmission is given by $C_{\mathrm{dt\_}su_i}$ in (2) when the transmit power allocated to the ith user is p_i. The object of transmit power allocation for users in U_{dt} is to maximize the sum of link capacity of involved users. Therefore, the objective function is defined as

$$\max_{C_{\mathrm{dt\_}su_i}} \sum_{i=1}^{N_1} C_{\mathrm{dt\_}su_i}. \tag{20}$$

Furthermore, the optimization problem of transmit power allocation for users in U_{dt} is formulated as

$$\begin{aligned} &\max_{C_{\mathrm{dt\_}su_i}} \sum_{i=1}^{N_1} C_{\mathrm{dt\_}su_i} \\ &\text{subject to: } 1)\ \sum_{i=1}^{N_1} p_i \leqslant \frac{N_1}{N} P_s, \quad 1 \leqslant N_1 \leqslant N, \\ &\qquad\qquad\quad 2)\ C_{\mathrm{dt\_}su_i} = \log_2\left(1 + \frac{|h_{su_i}|^2 p_i}{\sigma^2}\right), \\ &\qquad\qquad\quad 3)\ p_i \geqslant 0, \quad i = 1, 2, \ldots, N_1. \end{aligned} \tag{21}$$

In order to achieve the optimal transmit power allocation, the Lagrange multiplier λ ($\lambda \geqslant 0$) is introduced to solve the optimization formulation [15] given by (21). The Lagrange function $L(p_i, \lambda)$ is presented as

$$\begin{aligned} L(p_i, \lambda) &= \sum_{i=1}^{N_1} \log_2\left(1 + \frac{|h_{su_i}|^2 p_i}{\sigma^2}\right) + \lambda\left(\frac{N_1}{N} P_s - \sum_{i=1}^{N_1} p_i\right) \\ &= \sum_{i=1}^{N_1} \left[\log_2\left(1 + \frac{|h_{su_i}|^2 p_i}{\sigma^2}\right) - \lambda p_i\right] + \frac{\lambda N_1}{N} P_s. \end{aligned} \tag{22}$$

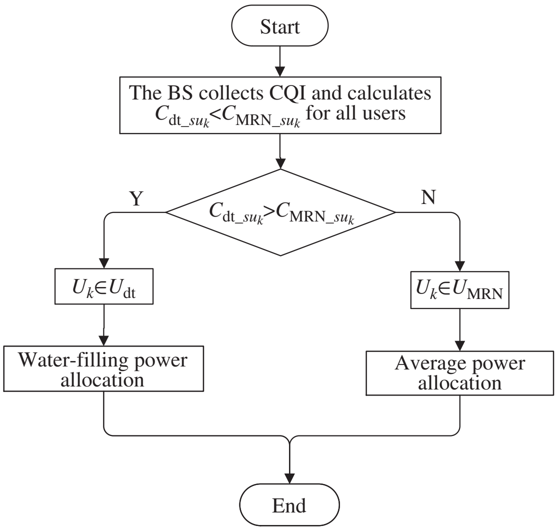

Figure 3 Flow chart of the mixed power allocation algorithm.

The derivative of Lagrange function $L(p_i, \lambda)$ in (22) for each variable of p_i is equal to zero when objective function in (20) achieves its optimum value, that is

$$\frac{\mathrm{d}L}{\mathrm{d}p_i} = \frac{1}{\ln 2} \frac{|h_{su_i}|^2}{\sigma^2 + |h_{su_i}|^2 p_i} - \lambda \triangleq 0. \tag{23}$$

To let $\eta = \frac{1}{\lambda \ln 2}$, Eq. (23) is further derived as

$$p_i = \left[\eta - \frac{\sigma^2}{|h_{su_i}|^2}\right]^+, \quad i = 1, 2, \ldots, N_1, \tag{24}$$

where $[x]^+ \triangleq \max\{x, 0\}$. η denotes the threshold representing the water-filling level. After the value of variable of η is specified, the optimal p_i can be calculated according to (24). In order to determine the optimal η, the quick iterative method in [18] is adopted. During each iteration, the water-filling level η is updated by

$$\eta \leftarrow \eta + \frac{\delta}{N_1} \left(\frac{N_1}{N} P_s - \sum_{i=1}^{N_1} p_i \right), \tag{25}$$

where parameter $0 < \delta < 1$ is the step size. The initial value of η is given as

$$\eta_0 = \frac{1}{N_1} \left(\frac{N_1}{N} P_s + \sum_{i=1}^{N_1} \frac{\sigma^2}{|h_{su_i}|^2} \right), \tag{26}$$

which can be obtained based on (24) under the condition of $\sum_{i=1}^{N_1} p_i = \dfrac{N_1}{N} P_s$.

4.3 The summary of the proposed algorithm

The overall processing flow chart of the proposed mixed transmit power allocation algorithm is depicted in Figure 3. The set of users are divided into set of U_{dt} and set of U_{MRN} by the BS. The water-filling transmit power allocation is applied for users in U_{dt} while the average transmit power allocation is applied for users in U_{MRN} according to (24) and (18), respectively.

5 Simulation results

It is assumed that the cell radius is 1000 meters and 100 users are distributed randomly within the cell. The total transmit power of the BS is constrained to 24 dBm [21] and the transmit power of MRN is assumed to be less than 20 dBm. The receiver noise figure of the user terminals and MRNs is 9 dB.

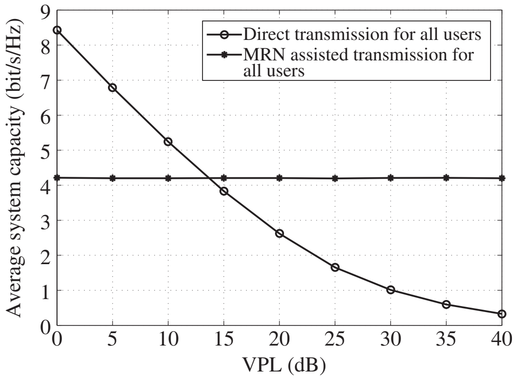

Figure 4 Average system capacity versus the parameter of VPL.

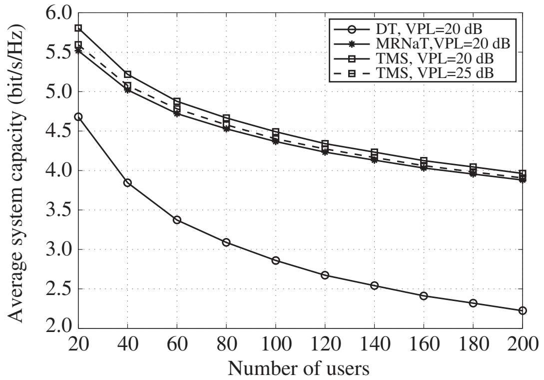

Figure 5 Average system capacity with different transmission modes.

The effect of parameter of VPL on the downlink average system capacity under two transmission modes is shown in Figure 4. When the direct transmission is utilized for all users, the average system capacity decreases as the value of VPL increases. When the MRN assisted transmission is used for all users, the average system capacity keeps unchanged since the effect of VPL is eliminated and radio propagation inside vehicles are assumed the same. Moreover, when the VPL is less than 14 dB, the average system capacity as the direct transmission is used for all users is higher than that as the MRN assisted transmission is used for all users. It is clarified that the MRN assisted transmission should be selected for all users instead of the direct transmission when the parameter of VPL is greater than 14 dB. The VPL is set as 20 dB in latter simulations unless otherwise specified.

The average system capacity versus the number of users with different transmission mode is shown in Figure 5. It is illustrated that when the number of total users increases, the average system capacity decreases through all three transmission schemes, i.e., direct transmission for all users, MRN assisted transmission for all users and transmission mode selection, under the certain constraint of total transmit power. It is demonstrated that the average system capacity obtained through the MRN assisted transmission is higher than that obtained through the direct transmission since the parameter of VPL is as high as 20 dB. It is clarified that the maximum average system capacity is achieved when the transmission mode selection is manipulated for each user by the BS. Furthermore, as the parameter of VPL increases to 25 dB, the average system capacity obtained through the transmission mode selection just decreases about 0.1 bit/s/Hz when the number of users is 100.

The average system capacity versus the number of users through different power allocation combining with different transmission mode is illustrated in Figure 6. When either direct transmission or MRN assisted transmission is employed for all users, it is shown that the system capacity obtained through water-filling power allocation is higher than that through average power allocation. Moreover, when direct transmission is used for all users, the improvement of system capacity is much more significant. By contrast, the difference gap of average system capacity between water-filling power allocation and average power allocation is quite slight when MRN assisted transmission is used for all users. It is implied that the water-filling power allocation should be applied for users through direct transmission. On the other hand, the average power allocation is applied for users through MRN assisted transmission in order to reduce algorithm implementation complexity.

In Figure 7, the performance of both the average power allocation and mixed power allocation algorithm combining with transmission mode selection are compared in terms of average system capacity under different VPL value. The simulation results validate that the system capacity is significantly increased when transmission mode selection is employed rather than direct transmission. Moreover, it is shown that the system capacity through the mixed power allocation proposed is higher than that through average power allocation based on transmission mode selection. It is also observed that the mixed power allocation further outperforms average power allocation when the VPL becomes 25 dB from 20 dB. As the number of users is 100, the capacity gain between the mixed power allocation and average power allocation is

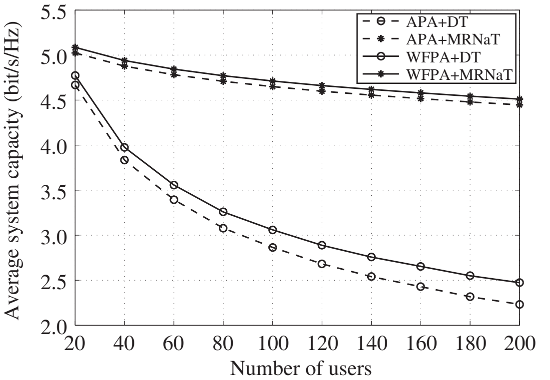

Figure 6 Average system capacity with different power allocation and transmission modes.

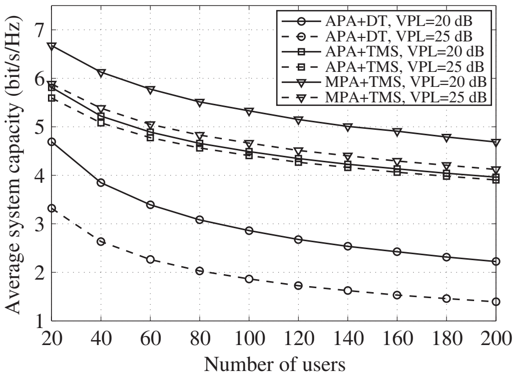

Figure 7 Average capacity with combination of power allocation and transmission modes.

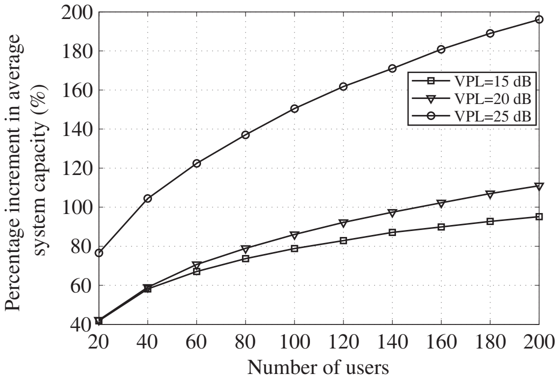

Figure 8 Percentage increment in average system capacity with different VPLs.

about 0.3 bit/s/Hz and 0.8 bit/s/Hz when VPL is 25 dB and 20 dB, respectively. When the value of VPL increases, less number of users tend to be selected by direct transmission and total transmit power for water-filling allocation decreases. Therefore, the gain of average system capacity is reduced.

In Figure 7, it is further shown the capacity gain between the mixed power allocation with transmission mode selection and average power allocation with direct transmission is about 2.5 bit/s/Hz as VPL is 20 dB. In order to illustrate explicitly the performance improvement given by the algorithm proposed, the percentage increment of average system capacity versus number of users with different VPLs are illustrated in Figure 8. The incremental percentage is defined as ratio of the capacity through mixed power allocation with transmission mode selection to the capacity through average power allocation with direct transmission. It is demonstrated that the percentage increment increases monotonously as the number of users increases. Moreover, the simulation results show that the percentage increment raises more sharply when VPL increases from 15 dB to 25 dB. Therefore, when the parameter of VPL becomes larger in the multi-MRN aided multiuser system, the average capacity improvement beneficial from the algorithm of mixed power allocation combing with transmission mode selection proposed in this paper increases significantly.

6 Conclusion and future work

In this paper, a novel power allocation algorithm in a multi-MRN aided multiuser system is proposed. The goal is to increase the average system capacity under the constraint of total transmit power. In order to maximize the average system capacity, users are firstly divided into two categories according to the transmission mode selection. Secondly, the water-filling power allocation is applied for users utilizing the direct transmission and the average power allocation is applied for users utilizing MRN assisted transmission. The simulation results demonstrate that the proposed algorithm outperforms the conventional average power allocation algorithm. Thanking to opinion of reviewers, it is noted that the joint optimization of transmission mode selection with water-filling power allocation for all users is further to be studied in the future.

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Conflict of interest The authors declare that they have no conflict of interest.

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