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A Mobile Multihop Relay Dynamic TDD Scheme for Cellular Networks

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***Abstract*—**In this paper, we present an analytical framework for the evaluation of the uplink performance of multihop cellular networks based on dynamic time division duplex (TDD). New wireless broadband protocols, such as WiMAX, WiBro, and 3G-LTE apply TDD, and mobile communication protocols under standardization (e.g., IEEE802.16j) are investigating mobile multihop relay (MMR) as a future technology. In this paper a novel MMR TDD scheme is presented, where the dynamic range of the frame is shared to traffic resources of asymmetric nature and multihop relaying. The mobile communication channel interference model comprises of inner and co-channel interference (CCI). The performance analysis focuses on the uplink due to the fact that the effects of dynamic resource allocation show significant performance degradation only in the uplink compared to time division multiple access (TDMA) schemes due to CCI [1-3], where the downlink results to be the same or better. The analysis was based on the signal to interference power ratio (SIR) outage probability of dynamic TDD (D-TDD) and TDMA systems, which are the most widespread mobile communication multi-user control techniques. This paper presents the uplink SIR outage probability with multihop results and shows that the dynamic TDD scheme applying MMR can provide a performance improvement compared to single hop applications if executed properly.

***Keywords*—**Co-Channel Interference, Dynamic TDD, Mobile Multihop Reply, Cellular Network, Time Division Multiple Access.

I. Introduction

In recent years, wireless asymmetric data services (i.e., different uplink and downlink ratios) have been requested tremendously and are expected to be even more popular in the future, considering the trend of the rapidly growing multimedia mobile communication market. Therefore, heavily multiplexed traffic patterns are expected to be more busty and time-varying in the future as well. Time division duplex (TDD) technology has gained much attention since TDD can be adaptively adjusted to handle asymmetric and time-varying traffic. Easy access to channel state information, reduced complexity of the radio frequency (RF) circuit design, and simpler radio plans are the other advantages of TDD systems. A major disadvantage of dynamic TDD is severe co-channel interference (CCI) due to uplink and downlink asymmetric transmission [1], [2]. To suppress CCI, mathematical analysis has been performed and the results show that the interference problem can be alleviated via using smart antennas [1], [3]. Intelligent time slot allocation and scheduling algorithms have also been proposed to improve the performance of D-TDD systems [3], [4].

Another solution to asymmetric traffic rate support is multihop relay techniques, which take advantage of dynamic traffic dispersion [5]. The authors of [5] shows that a number of ad hoc relaying stations can overcome the congestion by balancing the load among different cells in a cost-effective way. Furthermore, various multihop relay techniques of wireless mobile communication systems are under investigation widely due to their potential for lower transmission power consumption, more cost efficient system capacity enhancement, and higher service coverage [6], [7]. However, extra relay overhead, complex resource allocation for relaying support, requirements for accurate synchronization, and increments of implementation complexities are drawbacks of multihop relay technology.

In our study, the dynamic range of the frame is assigned to support unbalanced traffic and multihop relaying. Thus the dynamic range will be used to satisfy the required asymmetric channels and to enhance the throughput via MMR. In conventional TDD and TDMA systems with fixed uplink and downlink time slots, there is no cross interference between uplink and downlink transmissions. However, in dynamic TDD schemes, the asymmetric transmission of each cell results in cross interference among neighboring cells. Therefore, TDD systems are limited by interference comprised of inner and co-channel interference. Especially, the co-channel interference from the neighboring base stations (BSs) in downlink transmission, while the reference BS transmits in the opposite direction (i.e., the uplink cycle), is the most crucial event worthy of performance analysis (compared to TDMA systems).

In this paper, interference is evaluated in TDMA/D-TDD environment stochastically and the signal power is calculated in a theoretical manner. The uplink performance of multihop cellular networks with dynamic TDD is evaluated in the analysis of the SIR outage probability.

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II. System Model

A. System Model Assumptions and Definitions

Let us consider a multihop cellular structure, which is a hexagonal grid pattern (Fig. 1). There exists one BS, several multihop relay stations (RSs) and a number of mobile stations (MSs) in each cell, and MSs are assumed to be randomly positioned in a uniform distribution. In this model, the frequency reuse factor 7 is applied and interference at the reference cell is comprised of inner and outer interference. Inner interference is due to the multihop relay, and outer interference results from co-channel interference, which is caused by cells using the same frequency (i.e., 1st and 2nd tier in Fig. 1).

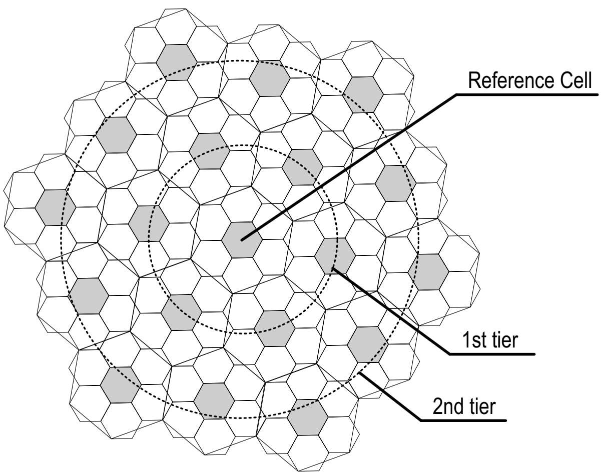


Fig. 1 Cell structure

B. Radio Model

The radio model of this paper is based on the path-loss power law for radio propagation [3] and the added transmission probability. According to this model, signal power will depend on the local mean power and shadowing effects in propagation [8], which can be described as:

$$P_r = \mu + \varsigma \tag{1}$$

$$\mu = P_t + G_t + G_r + 10\log_{10}(q_t) - 10\,n\log_{10}(R) \tag{2}$$

$$\varsigma = N(0, \sigma^2) \tag{3}$$

where P_r is the mean value of the received signal power at the reference cell, μ is the local mean power as described in (2), and ς represents the distribution of the propagation shadowing effect in (3). P_t is the transmitter power, G_t and G_r are respectively the transmitter and receiver antenna gains, q_t represents the transmission probability, n is path loss exponent, R is the distance between Tx and Rx, and σ is the standard deviation of ς.

C. Dynamic TDD Model

Fig. 2 shows a frame structure of dynamic TDD which is divided into three parts. The first part is the fixed uplink time slots, the second part is the dynamic range of the TDD frame, and the last part is the fixed downlink time slots. The number of slot for the dynamic range is limited by N' which is an integer from the uniformly distributed range $[0, N]$, and is dynamically assigned to asymmetric uplink and downlink support as well as multihop relaying services. m denotes the time slot index in the dynamic range.

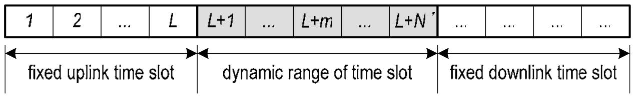
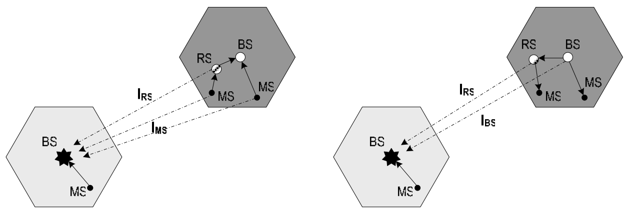


Fig. 2 Frame structure of D-TDD

D. Interference Model

Four interference scenarios can be discussed in this paper. The first is interference by MSs and RSs in the fixed uplink time slots, the second is due to BSs and RSs in fixed downlink time slots, the third is due to MSs and RSs in the dynamic range of time slots (Fig. 3(a)), and the last is due to BSs and RSs in the dynamic range time slots (Fig. 3(b)). System degradation in the downlink cycle at the reference cell is less sensitive than that in the uplink cycle. This stems from the fact that the propagation from BS to BS suffers less attenuation than that from a MS to BS, or RS to BS. Therefore, system performance evaluation in the uplink cycle is reasonable. Fig. 3 shows interfering cells that use the same frequency and interfering entities observed from the reference cell in the dynamic range.



(a) (b)

Fig. 3 Interference model of dynamic range time slot: (a) synchronous transmission, (b) opposing transmission

III. Signal to Interference Ration Calculation

A. Desired Signal Power Calculation

Desired signal power can be calculated using (1) for omni-directional antennas and the normalized antenna gain in the local mean power [3]. Thus, the desired signal power can be represented as:

$$P_S = \mu_{MB} + \varsigma_{MB} \tag{4}$$

where $\mu_{MB} = -10\,n_{MB}\log_{10}(R_d)$, $\varsigma_{MB} = N(0, \sigma^2_{MB})$, and path loss exponent between the MS and BS is 4dB.

Then, the probability density function of the desired signal power can be expressed as a Gaussian random variable, *X*:

$$f_{P_S}(\gamma) = N\left(\mu_{MB}, \sigma^2_{MB}\right) \equiv X^1_{MB}(\gamma) \quad (5)$$

B. Aggregate Interference Calculation

The aggregate interference in dB consists of all interference scenarios

$$P_I = 10\log_{10}\left(\sum_{i=1}^{\alpha} p_i\right) = 10\log_{10}\left(\sum_{i=1}^{\alpha}\left(p_i^{MS} + p_i^{BS} + p_i^{RS}\right)\right) \quad (6)$$

where p_i^{MS} is the transmission power from the MS at the neighboring cell c_i, p_i^{BS} is transmission power from the BS at neighboring cell c_i, p_i^{RS} is transmission power from the RS at neighboring cell c_i, and α is the number of neighboring cells. Each transmission power from different entities is as follows, and is expressed as a sum of co-channel interference from the neighboring cells. The meaning of neighboring cells is a cell in the 1st and 2nd tires, and uses the same frequency as the reference cell.

$$10\log_{10}\left(\sum_{i=1}^{\alpha}\left(p_i^{MS}\right)\right) \equiv X^{\alpha}_{MS} = N\left(\mu^{\alpha}_{MS}, \sigma^{\alpha}_{MS}\right) \quad (7)$$

$$10\log_{10}\left(\sum_{i=1}^{\alpha}\left(p_i^{BS}\right)\right) \equiv X^{\alpha}_{BS} = N\left(\mu^{\alpha}_{BS}, \sigma^{\alpha}_{BS}\right) \quad (8)$$

$$10\log_{10}\left(\sum_{i=1}^{\alpha}\left(p_i^{RS}\right)\right) \equiv X^{\alpha}_{RS} = N\left(\mu^{\alpha+1}_{RS}, \sigma^{\alpha+1}_{RS}\right) \quad (9)$$

Now, the aggregate interference in dB can express as follows.

$$P_I = X^{\alpha}_{MS} \oplus X^{\alpha}_{BS} \oplus X^{\alpha}_{RS} \quad (10)$$

where $\oplus$ is defined as an operator in order to express the sum of log-normal components, which have their own mean and variance. Schwarts and Yeh's method is applied to obtain the sum of log-normal components [9].

Standard deviation of random variables σ_{MS}, σ_{BS} and σ_{RS} are set respectively to 6, 8, 6 dB [3], and α is the total number of neighboring cells.

The probability density function of the aggregated interference can be represented as:

$$f_{P_I} = \sum_{N'=0}^{N} f_{P_I|N'}(\gamma) \cdot \frac{1}{N+1} \quad (11)$$

where $f_{P_I|N'}$ is the conditional probability density function (*pdf*) of the aggregate interference (provided that the number of dynamic range time slots is *N'*), which can be represented as (12), using the fixed time slot term $f_{P_I|F}$ and the dynamic range time slot term $f_{P_I|D}$.

$$f_{P_I|N'}(\gamma) = \left(\frac{1}{L+N'}\right)\sum_{m=1}^{L} f_{P_I|F}(\gamma) + \left(\frac{1}{L+N'}\right)\sum_{m=1}^{N'} f_{P_I|D}(\gamma, m) \quad (12)$$

$$f_{P_I|F}(\gamma) = 10\log_{10}\left(\sum_{i=1}^{\alpha} p_i\right) = 10\log_{10}\left(\sum_{i=1}^{\alpha}\left(p_i^{MS} + p_i^{RS}\right)\right) = X^{\alpha}_{MS}(\gamma) \oplus X^{\alpha}_{RS}(\gamma) \quad (13)$$

$$f_{P_I|D}(\gamma, m) = 10\log_{10}\left(\sum_{i=1}^{\alpha}\left(\left(p_i^{MS} + p_i^{BS}\right) + p_i^{RS}\right)\right) = \left(\sum_{k=0}^{\alpha} W(m,k) \cdot X(\gamma, k)\right) \oplus X^{\alpha}_{RS}(\gamma) \quad (14)$$

where $X(\gamma, k) = X^{k}_{BS}(\gamma) \oplus X^{\alpha-k}_{MS}(\gamma)$ and $W(m,k)$ is the probability of the downlink cycle in *k* number of neighboring cells at the m^{th} dynamic range time slot, which can be represented as,

$$W(m,k) = {}_{\alpha}C_k\left(\frac{m}{N+1}\right)^{k}\left(1 - \frac{m}{N+1}\right)^{\alpha-k}. \quad (15)$$

C. SIR Outage Probability

The signal to interference power ratio outage probability in this paper can be expressed as

$$P\{Outage\} = P\{SIR \langle \tau\} = \int_{-\infty}^{\tau} f_{SIR}(\gamma) d\gamma \quad (16)$$

where the outage probability is defined as the probability when the SIR is lower than a threshold value τ and the *pdf* of the SIR can be represented as a convolution of the *pdf* of the signal power and the *pdf* of the interference power.

$$f_{SIR} = f_{P_S}(\gamma) \otimes f_{P_I}(-\gamma) \quad (17)$$

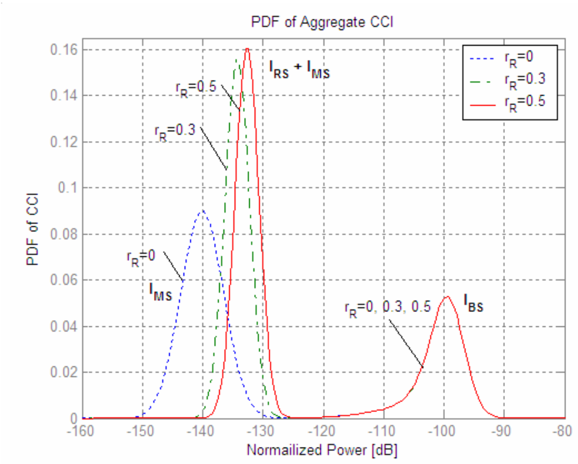
IV. Experimental Results

The multihop cellular network performance was evaluated using the *pdf* of the interference and the outage probability of the signal to interference power ratio. The system performance was evaluated in 3 different environments: without multihop relaying, multihop relaying in the entire frame, and multihop relaying in the dynamic range. Moreover different multihop relay rates are considered in the performance evaluation.

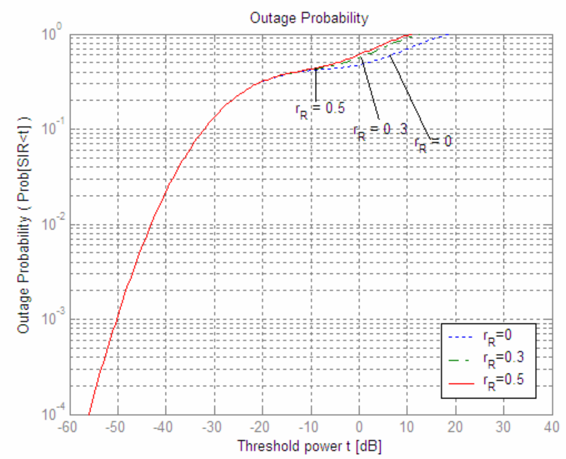
The parameters used in the simulation are defined as follows. The number of fixed uplink time slots is 33, the available maximum number of the dynamic range time slots is 20, up to 3 multihop relays exist in each cell, and the number of time slots for multihop relay is defined as H. The multihop relay rate is defined by the percentage of H over N and its values γ_R have been set as 0, 0.3, and 0.5 in the performance analysis.

Fig. 4 shows the *pdf* of the aggregated interference and the outage probability of the SIR in reference to the entire distributed multihop relay. In Fig. 4(a), interference from the BS, I_{BS} is dominant in all cases for γ_R = 0, 0.3, and 0.5. When adopting multihop relay to the entire frame, interference due to the RSs is caused and the system performance is degraded by I_{RS}.

Fig. 4(b) shows the outage probability of the SIR adopting multihop relaying to the entire frame. Same to the results mentioned above, performance degradation is mainly due to I_{BS} and it is also caused by I_{RS} when the threshold power τ in equation (16) is over -10dB. This result shows that I_{BS}, which is the dominant factor to the overall system performance, as well as I_{RS}, which makes an adverse effect to system performance, should be improved.



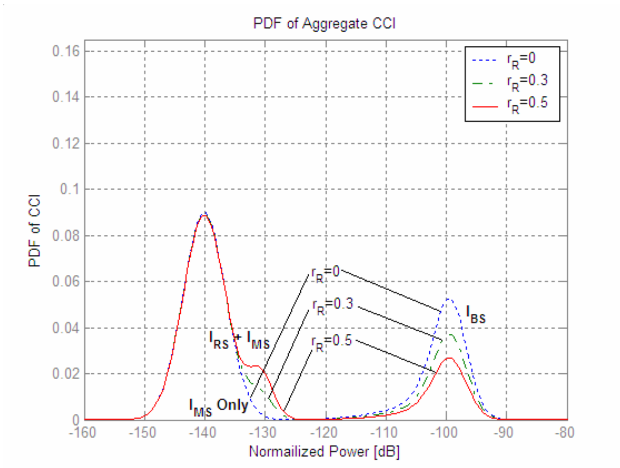
(a)



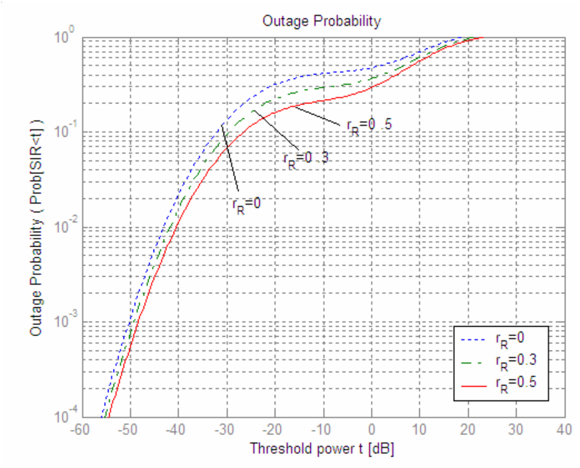
(b)

Fig. 4 Performance adopted multihop relaying to entire frame. (a) the *pdf* of aggregated interference, (b) the outage probability of SIR

Fig. 5 shows the system performance (i.e., the proposed dynamic TDD MMR scheme) when multihop relaying exists only in the specified portion of the dynamic time slots within the entire TDD frames. It can be observed in Fig. 5(a) that the distribution of interference power is different from that of Fig. 4(a). In addition, Fig. 5(b) shows the outage probability of the SIR.



(a)



(b)

Fig. 5 Performance adopted multihop relaying to dynamic range. (a) the *pdf* of aggregated interference, (b) the outage probability of SIR

Fig. 5(a) shows that the distribution of I_{BS} and I_{RS} is dynamically controlled with different γ_R values because the number of interference sources from neighboring cells decrease as the number of multihop relay time slots increases. This result is obtained because the number of influencing dominant interference sources, which are the BSs, decreased when multihop relay resource were bounded within the dynamic range of the TDD frames.

Another important result of Fig. 5(b) is that the system performance is significantly improved with increasing γ_R values for the entire threshold power range. This result implies that an adequate γ_R value needs to be chosen in order to satisfy the required asymmetric channels and to enhance the throughput via MMR technology.

V. Conclusion

In this paper a novel MMR TDD scheme is presented, where the dynamic range of the frame is shared to traffic resources of asymmetric nature and multihop relaying. The proposed MMR dynamic TDD model considers traffic resources of asymmetric nature, where multihop relay is assigned only to the dynamic range of the TDD frames. The applied cellular network interference model comprises of inner and co-channel interference. The analytical framework of the uplink performance of cellular networks has been investigated. The results reveal that, assuming that the multihop relaying was controlled with precision (i.e., maintaining accurate synchronization), the proposed dynamic TDD scheme applying MMR can provide a performance improvement compared to single-hop applications. However, it must be considered that accurate MMR control in cellular networks may not be an easy task, due to the mobility of the users. The analysis and results of this paper provides a method to accurately estimate the performance influencing factors of dynamic TDD systems in mobile multihop applications, such that future broadband mobile communication techniques can be developed with an improved overall system performance and wider service range through MMR technology.

References

[1] J. Li, S. Farahvash, M. Kavehrad, "Dynamic Time-Division–Duplex Wireless Local Loop," in *Proc. IEEE Vehicular Technology Conf.*, vol. 3, pp.1078-1085, Boston, MA, Sept. 2000.

[2] J. Li, S. Farahvash, M. Kavehrad, "Dynamic TDD and Fixed Cellular Networks," *IEEE Commun. Letters*, vol. 4, no. 7, pp. 218-220, July 2000.

[3] W. C. Jeong, M. Kavehrad, "Cochannel Interference Reduction in Dynamic-TDD Fixed Wireless Applications, Using Time Slot Allocation Algorithms," *IEEE Trans. Commun.*, vol. 50, no.1, pp.1627-1636, Oct. 2002.

[4] B. S. Bae, D. H. Cho, "An Integrated Scheduling Algorithm in a Wireless Packet Network with Dynamic TDD," in *Proc. IEEE 50th Vehicular Technology Conference (VTC 1999-Fall),* 1999.

[5] H. Wu, C. Qiao, S. De, O. Tonguz, "Integrated Cellular and Ad Hoc Relaying Systems: iCAR," *IEEE JSAC*, vol. 19, pp. 2105-2115, Oct. 2001.

[6] M. DeFaria, E. S. Sousa, "Effect of Intercell Interference on the SINR of a Multihop Cellular Network," *Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st*, vol. 5, pp. 3107- 3111, May 2005.

[7] Z. Dawy, S. Davidovic, I. Oikonomidis, "Coverage and Capacity Enhancement of CDMA Cellular Systems via Multihop Transmission," in *Proc. IEEE GLOBECOM 2003*, pp. 1147-1151, 2003.

[8] R. Prasad, "Universal Wireless Personal Communications," Artech House, 1998.

[9] S.C.Schwartz and Y. S. Yeh, "On the distribution function and moments of power sums with lognormal interferers," *Bell Syst. Tech. J.*, vol. 61, pp.1441-1462, Sept. 1982.