Joint Routing and Re-routing Control in Two-hop Cellular Relaying System

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***Abstract*—Relay is emerged recently as a promising solution not only to improve coverage but also end-to-end date rate. How to manage the radio resources effectively for the integrated cellular network are the key issues to be studied. The paper re-evaluates the traditional concept of adjustment and optimization for the call routing and congestion control as call routing and admission control (CRAC). With respect to the mobility and the variable wireless environment, the call re-routing algorithm which implements the intelligence and adaptability is also studied as call re-routing control (CRRC). The joint routing and re-routing control (JoRR) algorithm is proposed to realizes the global optimization of the existing algorithms Two schemes, namely Centralized Architecture (CA) and Decentralized Architecture (DA), are studied to implement the JoRR algorithm whose criterion is selected by considering the characteristics of the integrated cellular system and the tradeoff between the cost and the effectivity. At last, a set of system-level performance evaluation is provided based on the characteristics of the new network architecture.**

Keywords- Relay, routing, Call routing and admission control (CRAC), Call re-routing control (CRRC), Joint Routing and Re-routing Control (JoRR)

I. INTRODUCTION

Modern cellular networks need to provide not only high quality voice service for customers, but a large amount of data transfer service as well, such as wireless internet access, multimedia, file transfer and downloading. The rising demand for high data rate services in future wireless networks calls for the demand of advanced strategies at various layers.

The cellular concept is based on the sub-division of geographical area into a number of smaller areas to be covered by the network consisting of a group of cells. The cell boundaries' co-channel interference prevents the channel resource of a system to be fully available for users and lead to the limitation of the cell coverage and system throughout. Relaying is not only efficient in eliminating black spots, but more importantly, it may extend the high data rate coverage range of a single base station (BS); therefore cost-effective high data rate coverage may be possible through the augmentation of the relaying capability in conventional cellular networks [1]. The interest in the integration of "multi-hop" capability into the conventional wireless networks has been in various forms. For instance, mesh networks, cellular multi-hop networks, cellular ad-hoc networks and ODMA (opportunity-driven multiple access) [2][3].

There are many challenges in realizing an integrated cellular relaying system; one of which is an overall routing issues that the MT wishes to transmit information to BS and obtain a source route to the destination. Yet, even with a well designed and tuned routing algorithm, it is still not clear whether the system capacity will cost-effectively increase, mainly due to that the radio resource management algorithms may also limit the system performance [4][5][6]. For instance, traffic is likely to be unbalanced in real system, the throughput of the entire system may be decreased, and call blocking and dropping may occur due to localized congestion. By considering load balance in routing a user may be routed to a low loaded cell therefore alleviating the congestion and improving the performance. In summary, combined design and optimization of routing algorithms and other radio resource management functions [7] are crucial to fully exploit the potential benefits of the relaying.

At last, it should be emphasized that the routing mechanism concerned in the integrated cellular network is not tightly combined with the link adjustment, mobile environment and etc. To meet various QoS requirements in mobile communication, a re-routing mechanism as well as routing mechanism is necessary in order to timely trigger the route discovery mechanism to meet the challenge in the existing integrated cellular relaying network. With the integrated cellular relaying network, a centralized re-routing control across BS or RN in different cell is expected to enable the resources to be fully utilized; while, decentralized re-routing control mainly consider intra-cell link adjustment is less complex to implement. In conclusion, carefully design and optimization of routing and re-routing mechanism are important for the integrated cellular relay system.

This paper proposes an effective joint routing and re-routing algorithm for the two-hop cellular relaying system that selects the route with the best quality. Besides, to overcome the limitation of the data rate for the cell boundaries, a relaying channel allocation is proposed to better utilize the radio resources. The call routing and admission control (CRAC) algorithm considers load balancing in routing and performs the congestion control when overloaded. The call re-routing control (CRRC) maintains the reliable communication and dynamically adjusts the MS to the other BS or RN so as to obtain the better service. Both The Centralized Architecture (CA) and Decentralized Architecture (DA) are evaluated. At last, the paper proposes the Joint Routing and Re-routing Control (JoRR) algorithm and provides the system-level performance evaluation for a multi-cell environment in the integrated cellular relaying network.

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II. System Model

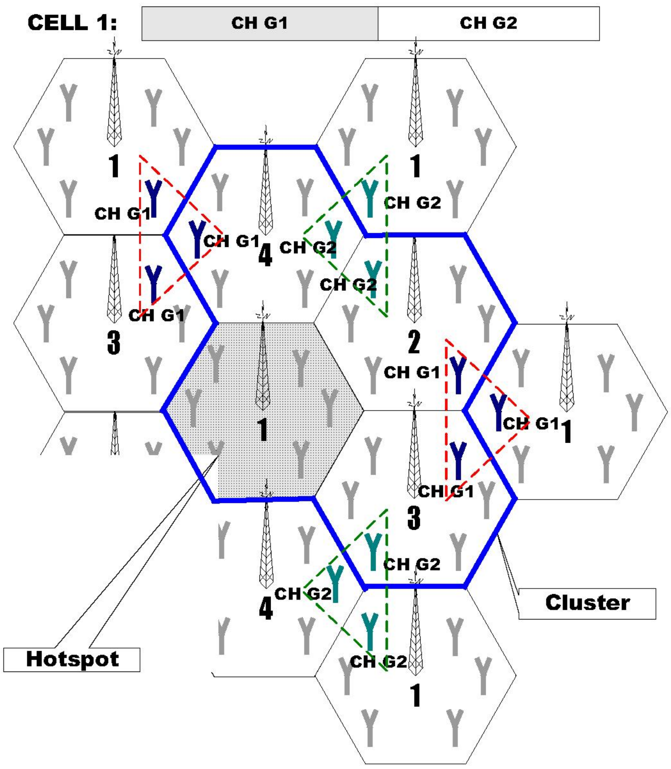

Figure 1. Two-hop cellular relay system model

The model of integrated cellular relaying system is presented in Figure.1. The BS is located in the center of the hexagonal cell and six fixed RNs are placed at a circle in each cell as new network elements different from the current cellular infrastructure. The MT can connect to the BS either directly or indirectly via a two-hop transmission by the RN. Thus, the way to connect the different network elements could be seen like tree topology rooted at BS. The multiple access scheme considered here is based on TDMA where a channel is uniquely identified by a timeslot and a frequency carrier.

In this paper, a "pre-configured" relaying channel allocation scheme is adopted to reuse the already used channels in the network [7]. However, it runs the risk of causing potentially excessive co-channel interference. Therefore, careful channel selection may be necessary. The "pre-configured" relaying channel allocation scheme is base on two basic principles. First, to avoid self-interference, a RN is not allowed to reuse any channel in the same cell but reuses a part of the channels from the farthest cell. Second, in order to avoid the RNs that reuse channels from the same cell use the same channel, all channels belonging to a certain cell are equally divided into several disjoint groups, and RNs reuse channels only from the predetermined groups. As Figure.1 shown, all channels belonging to cell 1 are divided into two groups, denoted as ChG1 and ChG2, which are reused by the RNs marked blue and green respectively. Thus, there is no co-channel interference between the RNs in a cluster. The three neighbor RNs' channels are put into a channel pool. Each RN can use any free channel in the pool. They share the channels in order to improve the resource utilization when compared with that in [7].

III. Joint Routing and Re-routing Control

A. Call Routing and Admission Control(CRAC)

In the proposed cellular relay network, the MT shall choose either the direct link or two-hop link with relay assistance. The routing mechanism, which discovers routes initially for MT, plays a very important role not only to guarantee the QoS but also to perform congestion control in order to control the unbalanced traffic.

The proposed CRAC algorithm should not only consider the user's own transmission quality but also take into account the resource utilization efficiency from the perspective of the system. First, the criterion to determine with which node (a BS or one of the RNs) a MT will be connected is based on the received power. Second, when the selected BS or RN has free channels, a call access request can be accepted with the selected direct transmission link or the relaying link assigned. On the other hand, the MT may be transferred to another cell when the home cell is congested (the special function, congestion control, of the proposed CRAC). The CRAC algorithm can be identified as 7 steps:

1. Select a BS with the highest received power (*RP*) as the possible BS (home BS) responsible for transmission.

$$BS_{SEL-ho} = \arg \max_{all\ k \in K} \{RP_{BSk}\} \tag{1}$$

where K is the set of the BSs in the system, BS_{SEL-ho} is the selected home BS, and RP_{BSk} is the received power at the target MT from the kth BS.

2. Check the available channels in BS_{SEL-ho}, and if there is no free channel (means home cell is overloaded), skip to step 5.
3. Among M RNs, select the RN providing the maximum received power in BS_{SEL-ho} as the possible RN.

$$RN_{SEL-ho} = \arg \max_{all\ m \in M} \{RP_{RNm}\} \tag{2}$$

where RN_{SEL-ho} is the selected RN in BS_{SEL-ho}, and RP_{RSm} is the received power at the MT from the mth RN in BS_{SEL-ho}. If received power of RN_{SEL-ho} is higher than BS_{SEL-ho}, skip to 4, else skip to step 7;

4. Randomly allocate an available channel in RN_{SEL-ho} to the MT and skip to step 7. Here, a random selection scheme is adopted to prevent the co-channel interference from increasing to unacceptable levels. If there is no free channel in RN_{SEL-ho}, skip to step 7.
5. Among N RNs in the neighbor cells, select the RN providing the maximum received power as the possible RN responsible for relaying.

$$RN_{SEL-neb} = \arg \min_{all\ n \in N} \{RP_{RNn}\} \tag{3}$$

where $RN_{SEL-neb}$ is the selected RN in one neighbor cell, the corresponding BS is selected as $BS_{SEL-neb}$, and RP_{RSn} is the received power at the MT from the nth neighbor RN.

6. Randomly allocate an available channel in RSSEL-neb to the MT. If there is no free channel in RSSEL-neb, delete RSSEL-neb from set N, and skip to step 5 for the case of set N is not null, and else, reject this call access request and then exit the CRAC algorithm.
7. Randomly allocate a free channel from the selected BS to the MT (for direct transmission) or the RS (for relaying), and then exit the CRAC algorithm.

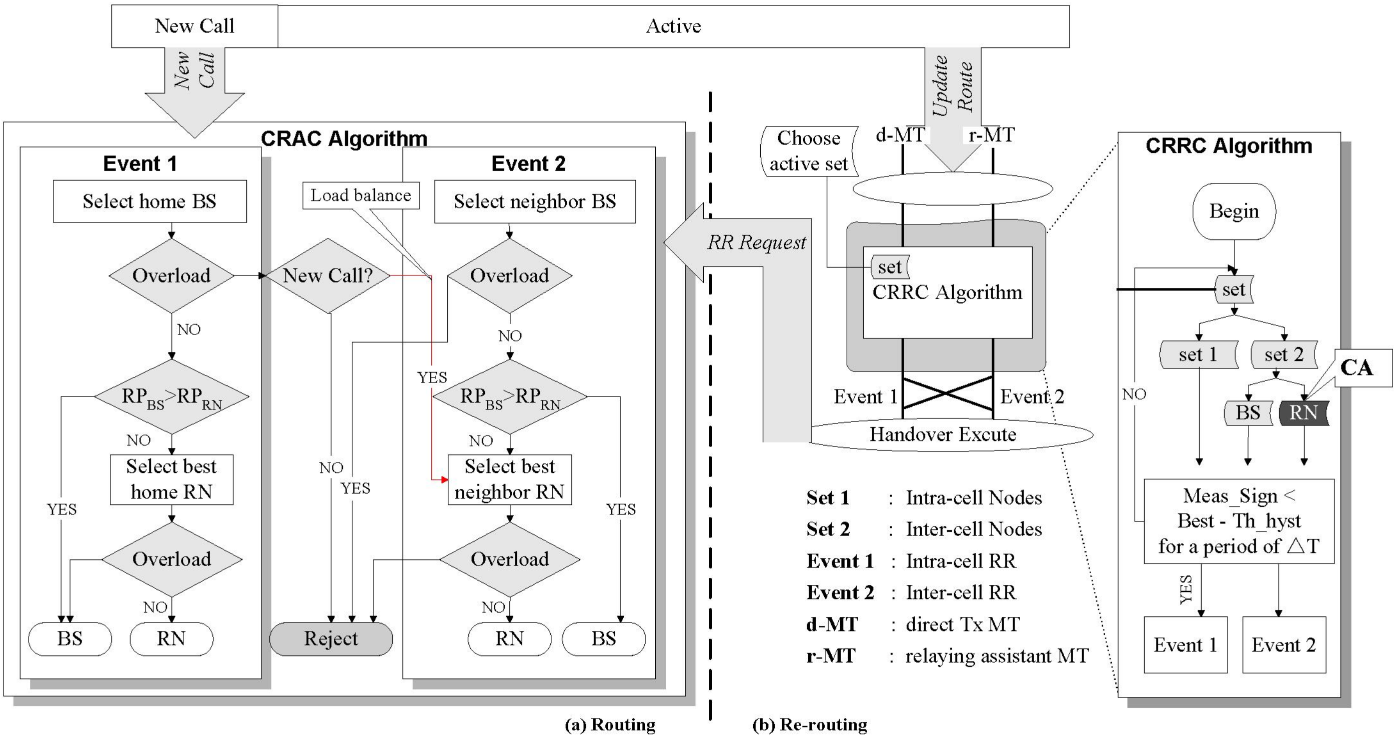

Figure 2. Joint Routing and Re-routing (JoRR) Control in Two-hop Cellular Relaying System

Fig.2 gives the flowchart of the CRAC algorithm when N=1. Based on CRAC algorithm with load balance, the MT can utilize the whole system channels more efficiently by relaying some services to the neighbor cells via the RN's link.

B. Call Re-routing Control(CRRC)

Due to the mobility and variable wireless environment, it is important to investigate the call re-routing algorithm that implements the intelligence and adaptability of the integrated cellular relaying network. The re-routing (RR) occurring in the integrated network can be classified as inter- and intra-cell RR that consists of several parts of upcoming procedures between BS, RN and MT. The basic RR triggering criterion is the received power from BS or RN.

Figure.3 shows the flowchart of the CRRC algorithm. The active set includes both inter-cell nodes and intra-cell nodes. Compared with the measured signal power with the current received power, the system may trigger either an inter-cell RR or an intra-cell RR.

C. Joint Routing and Re-routing control

Joint routing and re-routing control (JoRR) control not only enables the MT to detect the proper routes initially, but also dynamically choose the best link for guaranteeing QoS. It combines the routing and re-routing control to get a global optimization. Figure.2 shows the relation between routing and re-routing control.

1. When a new call initials, the routing algorithm detects the proper routes and perform the load control;
2. When the MT was in active mode, it timely send updating route request to the re-routing module. The re-routing algorithm determines whether a RR request should be triggered;
3. The RR request is sent to the routing module, and the routing algorithm re-detects the proper routes for the MT;

The three steps cover the routing and re-routing procedure. The JoRR control makes decision for the MT to choose the optimal route and perform the load control.

D. CA- and DA-based JoRR algorithm

The call re-routing control (CRRC) algorithm should not only consider the received power but also the upcoming RR cost such as delay, dropping and etc. Two schemes, namely Centralized Architecture (CA) and Decentralized Architecture (DA), are presented as candidates to investigate the CRRC with their respective advantages and disadvantages. Four types of inter-cell RR (RN-RN, RN-BS BS-BS and BS-RN) have longer handover delay than intra-cell RR. CA-based JoRR (CA/ JoRR) disallows the inter-cell RN-RN and BS-RN that have higher handover delay but only allows inter-cell BS-BS, RN-BS and intra-cell RR. DA-based JoRR (DA/JoRR) allows all types of RR so as to always choose the optimal link. It can be inferred that DA/JoRR, which has longer handover delay, is more effective to guarantee QoS and more attractive in applying to low BER requirement services; while CA/JoRR, which has fast handover response and less signaling cost, is more promising when applying to voice services.

The RR request flow of CA/JoRR and DA/JoRR is described in Figure.3. The intra-cell BS/RN nodes and inter-cell BS/RN nodes are selected as candidate RR targets and put in an active set. CA/JoRR algorithm excludes the inter-cell RN in set 2 that causes high RR cost such as handover delay. Then, compared with the measured signal power from the nodes in the active set, the MT selects the best node and sends a RR request to the network.

IV. SIMUATION RESULTS

This section presents the simulation results to evaluate the proposed CA-based (CA/JoRR) and DA-based (DA/JoRR) JoRR algorithms. The investigated system consists of 7 clusters each with 4 hexagonal cells as shown in Figure.1. The number of channels in each cell is N=120. The cell marked "1" in the center cluster is a hotspot in which the number of the users is 1.2 times of that in a non-hotspot cell. The RN position is chosen as 2R/3 from the BS. The RN digitally decodes and re-encodes the relayed signal before retransmission to MT.

TABLE I. LIST OF THE SIMULATION PARAMETERS

PARAMETERS	Values
Reuse Factor	4
Cell Radius (R)	0.5km
RN Radius	2/3*R
Number of RNs in One Circle	6
Standard Deviation of Shadowing	8dB
Path-loss Exponent for Home Cell (BS-MT; BS-RN; RN-MT)	(4; 2.5; 4)
Path-loss Exponent for Other Cells	4
Carrier Frequency f	2GHz
Down Link Max BS Power (P_1)	1W
Down Link Max RS Power (P_2)	0.2 W
Noise Power	-132 dBW
Channels per Cell	120
Users per Cell	[70 80 90 100 110]
Total Bandwidth per Cluster	2MHz
Avg. MT Speed	5m/s

Figure.3 shows the results in the form of blocking rate. When the system load increases to 100 users per cell or more, corresponding to 83% of full load, the blocking rate of new users increases rapidly. However, load balance strategy reduces the blocking rate from 20% to less than 5%, and even less than the Erlang B formula Thus, load balance can decrease the whole cluster's blocking rate so as to enable the system to accept more users.

Figure.4 shows the results in the form of normalized serving traffic load versus average MT numbers in a cell. Normalized cell bit rate is defined as the total cell throughput divided by bandwidth. The spectrum efficiency of CA/JoRR and DA/JoRR are about 1.5 times than traditional direct transmission system when assuming the same cell radius and BS transmit power. Also, Compared with the DA/JoRR, CA/JoRR obtains a gain round 10%~20% in terms of normalized serving traffic in a cell. This because CA/JoRR always select the best link for the MT, however, DA/JoRR neglects the potential better RN links from the neighbour cell RN.

Figure.5 shows the results in the form of the cell-edge user bit rate (5th percentile) versus normalized serving traffic load. Cell-edge user bit rate is defined as the user throughput at the 5% point of the C.D.F. The results shows that CA/JoRR provides better performance than DA/JoRR and traditional system given a certain serving traffic. The reason is that the DA/JoRR algorithm excludes the inter-cell RN in set 2,which causes high RR cost such as handover delay but may be beneficial for the cell edge MT to opt for a better link than intra-cell RN.

Figure.6 presents the results in the form of the average number of RR request in a cell per second versus number of users per cell. With RR a MT try select the link with the best quality. CA/JoRR has more R requests than DA/JoRR when load balance control is performed because the MTs always choose the best BS/RN. This is not the reason. It should be shown that CA leads to more MTs connecting to neighbor cells when overloaded The CA/JoRR algorithm leads to more MTs connecting to neighbor cells when overloaded. In that case, the MTs attempt to send RR request to the original cell with better link quality; thus, it inevitably increases the RR request than the schemes without load balance.

The RR procedure consists of several parts of upcoming procedure between BS, RNC, MS, etc. Inter-cell RR from RN to RN has higher delay than intra-cell handover. Explicitly evaluation of the RR delay requires explicit signaling and procedure of the connection setup and release for the RR. This is out of our research scope. For a roughly evaluation, different type of handover is assigned a different delay value.

TABLE II. EVALUATION OF HANDOVER DELAY

PARAMETERS	Source - Target	Delay
Intra-cell RR	BS - RN	100 ms
	RN - BS	50 ms
	RN - RS	100 ms
Inter-cell RR	BS - BS	200 ms
	BS - RN	300 ms
	RN - BS	200 ms
	RN - RN	300 ms

Table.2 gives the handover delay for each procedure. Some reference describes more detailed handover procedure and delay calculation [9][10]. Figure.7 shows average handover delay of DA/JoRR is strongly lower. The reason is that DA/JoRR has more intra-cell RN/RN, RN/BS, BS/RN handover which have a lower handover delay; Average handover delay of CA/JoRR is higher because some type of RR between inter-cell BS/RN and RN/RN have higher handover delay.

V. CONCLUSION

The Joint Routing and Re-routing Control (JoRR) algorithm for a two-hop integrated cellular relay system are presented in this paper. Besides a co-channel interference avoidance relaying channel reuse scheme, the JoRR algorithm includes the CRAC and CRRC algorithms that involve the modification and optimization of the call admission, re-routing and congestion control for an integrated cellular relay network. Two schemes, CA-based JoRR and DA-based JoRR are proposed to implement the routing and re-routing and meet various QoS requirement. The simulation results show that compared with the traditional single-hop cellular system, the integrated cellular system can obtain better system performance, such as cell-edge bit rate and cell throughput Moreover, the CA/JoRR can improve both the cell-edge throughput and the whole cell throughput compared with the DA/JoRR, whereas the DA/JoRR reduces the RR intensity compared with the CA/JoRR. The two schemes can complement each other as a tradeoff between cost and effectivity.

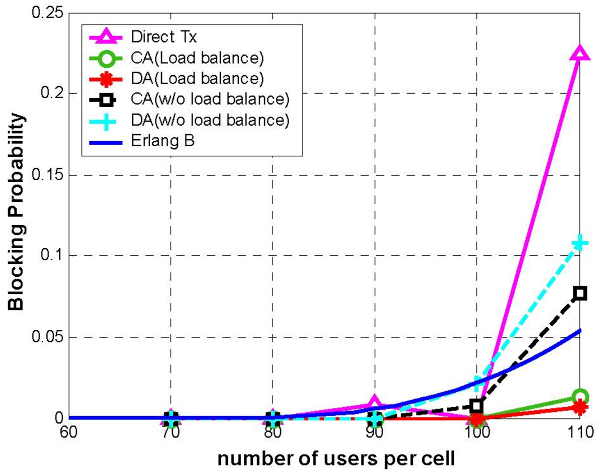

Figure 3. Call blocking rate (avg. in a cluster)

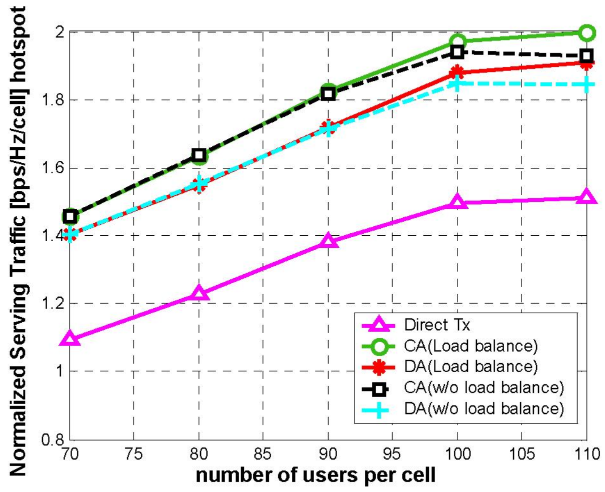

Figure 4. Throughput (5th percentile) vs. number of user per cell

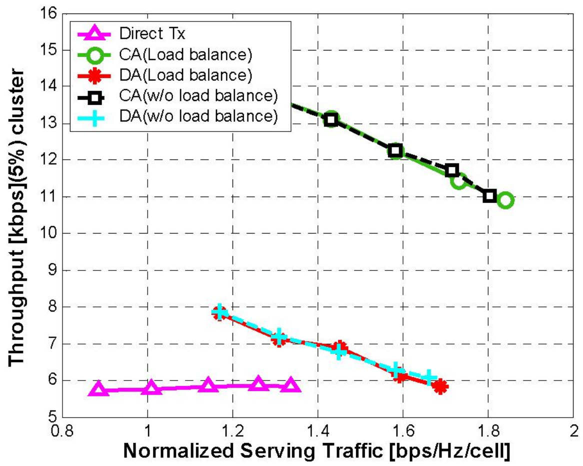

Figure 5. Throughput (5th percentile) vs. normalized serving traffic

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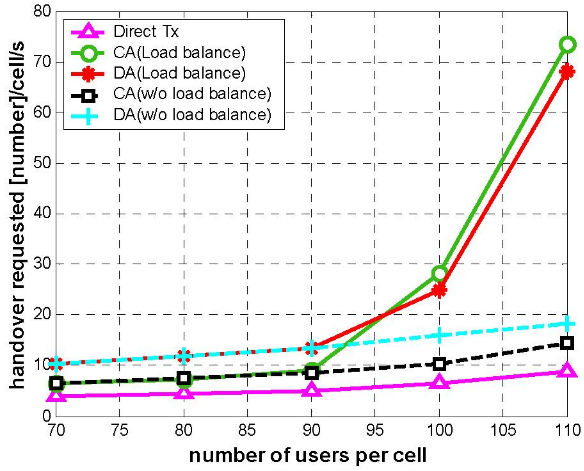

Figure 6. handover requested rate ([number]/cell/s)

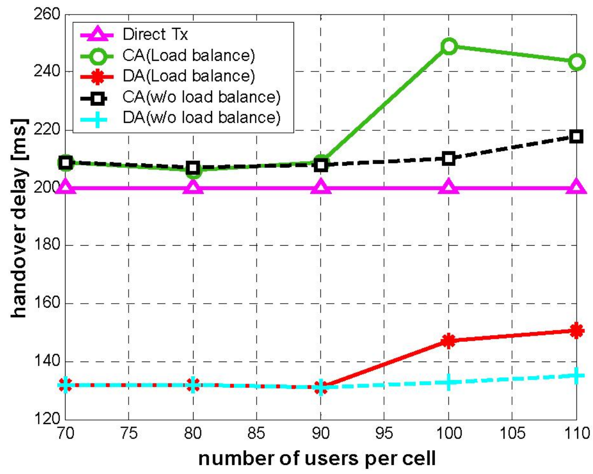

Figure 7. Handover delay vs. users per cell

REFERENCES

[1] R. Pabst, B. H. Walke and et al., "Relay-based deployment concepts for wireless and mobile broadband radio," Communications Magazine, IEEE, vol. 42, pp. 80 – 89, Sept. 2004.

[2] H. Yanikomeroglu, "Fixed and Mobile Relaying Technologies for Cellular Networks," 2nd Wksp. Apps and Svcs. in Wireless Networks, Paris, France, 3–5 July 2002, pp. 75–81.

[3] MeshNetworks, http://www.meshnetworks.com.

[4] J Boyer, DD Falconer, H Yanikomeroglu, "Multihop Diversity in Wireless Relaying Channels", IEEE Transactions on Communications, 2004

[5] W. Zirwas, M. Lampe, H. Li and et al., "Radio resource-management in cellular multihop networks", WPMC'02, 2002.

[6] S. Mukherjee and H. Viswanatham, "Resource allocation strategies for linear symmetric wireless networks with relays", IEEE ICC'02, 2002.

[7] H. Wu, C. Qiao, S. De and O. Tonguz, "Integrated cellular and ad hoc relaying systems: iCAR" , IEEE Journal on Selected Areas in Communications (JSAC), vol. 19, pp. 2105-2115, October 2001.

[8] Huining Hu, Halim Yanikomeroglu, David D. Falconer, and Shalini Periyalwar, "Range extension without capacity penalty in cellular networks with digital fixed relays", IEEE Globecom'04, 2004.

[9] 3GPP, "TS25.815: Signaling enhancements for Circuit-Switched (CS) and Packet-Switched (PS) Connections Analyses and Recommendations", v0.4.2, Nov 2005.

[10] 3GPP, "TS25.853: Delay Budget within the Access Stratum", v4.0.0, Mar 2001.