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Coverage and Capacity Enhancement in Cellular Network By Using Digital Relays and Load Balance

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Abstract: The variation of the distances between the base station and the border areas of hexagon shape of the mobile leads to the existence of certain dead zones (gaps) in the coverage at the border of the cell. Relay station is a promising solution to enhance coverage in these gaps. Furthermore, these relay stations can also be used to enhance the capacity of network by using Load Balance Technique. This study discusses the effect of adding three relay stations to the network. Results show that with proper frequency plan for assign channels to relays, relaying can have a significant effect on the coverage, the outage probability, average spectral efficiency and call blocking probability.

Key words: Dead zones, load balance, network, coverage enhancement, capacity enhancement, Iraq

INTRODUCTION

Coverage has invariably been a major concern for cellular service providers. In a built up urban environment, the radio signal decays very rapidly as the distance between the transmitter and receiver increases. There are several types of coverage of cellular system and every type has some area with low and weak signal or without signals which leads to communication blockage in these areas (Stallings, 2005). A number of techniques have been used to combat coverage holes and obtain full coverage for cellular systems, techniques like Integrated Cellular and Ad hoc (iCAR), Multi-hop Cellular and Cellular IP in which the service provider attempts to put all of its resources at the network to get best coverage (Wu *et al*., 2001; Sreng, 2002).

The existing cellular system can provide good voice service. But as the mobile user increasing and the popularization of wireless access to internet by mobile phone, more bandwidth is needed for the wireless data traffic (Huining *et al*., 2004). Another problem facing the cellular network service providers worldwide is coping with congestion where the amount of traffic generated by the users is more than the capacity of the service providers' infrastructure. Coverage and capacity are related to each other and have effect on the design process. There are many telephone customers much larger than the number of available resources but not every customer makes or receives a telephone call at the same time (Yanmaz *et al*., 2003). In this study, the relays are proposed as a solution to extend the coverage to dead spots or coverage holes that are not covered by the base station, these relays also used to enhance system capacity by load balance of available resources. The simulation tool used in this research is Matlab R2008a.

MATERIALS AND METHODS

System model: The basic idea of the proposed system is to add a three digital fixed relays to enhance coverage in gaps, so that the signal between the mobile station and base station can be relayed. These relays are wireless communication devices which may have limited equipments (not like BTS). There are two types of relaying analog fixed relaying and digital fixed relaying. The main difference between analog relaying and digital relaying is that the analog relay simply amplifies the entire signal it receives and re-transmits it while the digital relay performs decoding and re-encoding of the receiving signal before re-transmitting it to ensure it only forwards the signal not the noise (Hu, 2003). Each relay has three connections one with base station of the same cell and the other with the two closest relays. If mobile communicate with relay and it does not have free channel, its call will not drop, actually it will be routed by using nearest relay as shown in Fig. 1. The following fairly simple Propagation Model can be used in the simulation (Wu *et al*., 2001):

$$P_r = P_t\left(\frac{G_t G_r}{P_L}\right)X_\sigma \quad (1)$$

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Where:

- P_t = The transmitted power
- P_r = The received power
- G_t and G_r = The antenna gains of transmitter and receiver for receiving antenna gain set to 1 and for the sector transmitting antenna set equal to 15
- X = A zero-mean Gaussian distributed random variable (in dB) with standard deviation of σ (in dB) representing the lognormal shadowing
- PL = The average pathloss

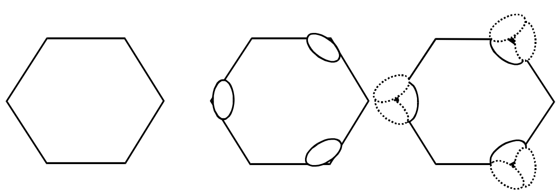

Fig. 1: Cellular layout with 120° directional antenna used at relays; a) without relay; b) with relay and c) with relay and with load balance

The average pathloss can be calculated as follows (Hu, 2003):

$$P_L = \left(\frac{4\pi d_0 f}{c}\right)^2 \left(\frac{d}{d_0}\right)^{\gamma} \quad (2)$$

Where:

- d_0 = The reference distance and is set to 10 m
- γ = The propagation exponent

For such scenario cellular system need channeling re-arrangement to find suitable channel assignment for the added relay station which is used to enhance the coverage. An optimized frequency plan is used to avoid interference problem.

The proposed method uses the same frequency channel of BTS in the same cell but the antenna of the relay radiates in opposites direction and self interference should be avoided due to sectorization effect (Fig. 2).

Simulation parameters and procedure: A Hexagonal Cellular System with different cluster size (4 and 7) has

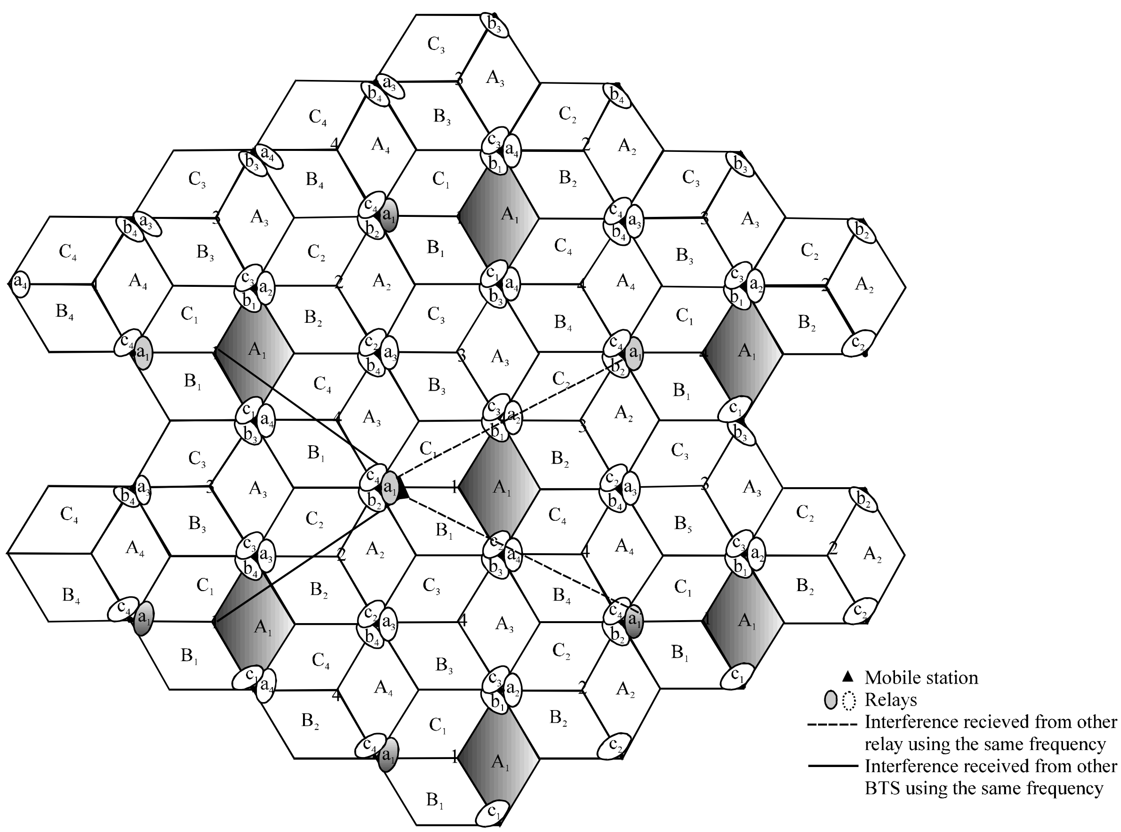

Fig. 2: Frequency plan and interference sources effects of base station and relay on mobile station

been simulated to evaluate the performance with first tier of interferers. The Simulation Model support only downlink scenario and the simulation parameters can be summarized as follows:

- Pathloss propagation exponent is taken equal to γ = 4 (William *et al*., 2004)
- Adjacent-channel interference is neglected
- Lognormal shadowing with 0 dB mean and 8 dB standard deviation is used (Krzysztof, 2002)
- Different types of antennas (Omni and Directional sector antennas) with front to back gain ratio = 15 dB for sector antenna are simulated
- Transmitted power of the BTS is 5 watt and relay transmit power is 0.1 watt
- Base station coverage of sector type (120°)
- The minimum received power (min^{-1}) = -128 dB (Eberspacher, 2009)

Simulation procedure can be summarized as follows:

- Locate the mobile station in hexagonal cell area which is part of cluster size (N) of 4 and 7
- The received signal ilevel is determined as the movement of user from center toward edge of cell
- Interferences from other cells can be found by determining the distance from first tire co-channel interferences as:

$$I_{total} = I_1 + I_2 + \ldots\ldots + I_M \quad (3)$$

where, M is the number of interference signal from base station and relays that use same frequency (Fig. 2):

- Mobile station selects the signal with high SIR (from either BTS or the relay)
- Outage probability is calculated by taking the required number of samples. Evaluation process depends on the threshold (SIR0) (Hu, 2003)
- System blocking probability is examined according to the Erlang B formula (Rappaport, 2002):

$$P_B = \frac{A^C/C!}{\sum_{k=0}^{C} A^k/k!} \quad (4)$$

Where:
A = The maximum carried traffic
C = The number of trunked channels

Blocking probability will be given in three scenarios:

- Without relay and load balance
- With relay-without load balance
- With relay and load balance
- Spectral efficiency is calculated as the carried traffic per cell divided by the bandwidth of the total system and the area of a cell (Hammuda, 1998)

RESULTS AND DISCUSSION

A cellular system with cell radius equal to 2000 m is simulated. It is assumed that the user move from center toward the edge of cell. The simulation results are shown in Fig. 3-10. Figure 3 shows the signal power level

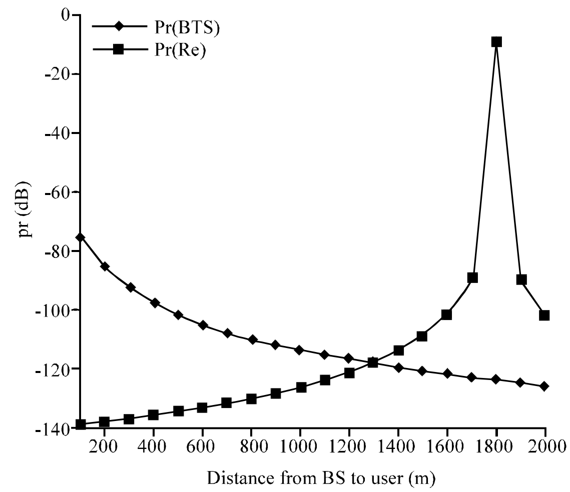

Fig. 3: Pr received at MS from base station and relay (when relay uses Omni directional antenna and it is position at 1800 m)

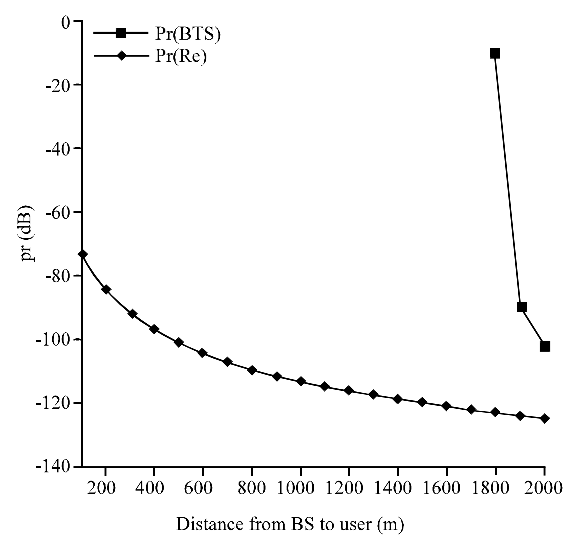

Fig. 4: Pr received at MS from base station and relay (when relay uses 120° sector directional antenna and its position at 1800 m)

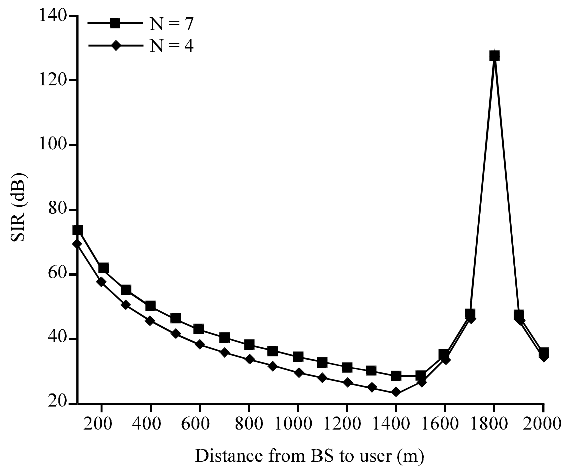

Fig. 5: SIR values for different cluster sizes with relay of Omni directional antenna (relay position at 1800 m)

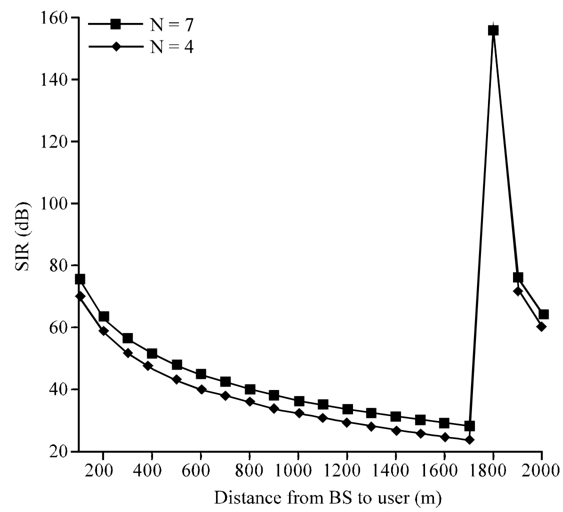

Fig. 6: SIR values for different cluster sizes with relay of 120° sector directional antenna (relay position at 1800 m)

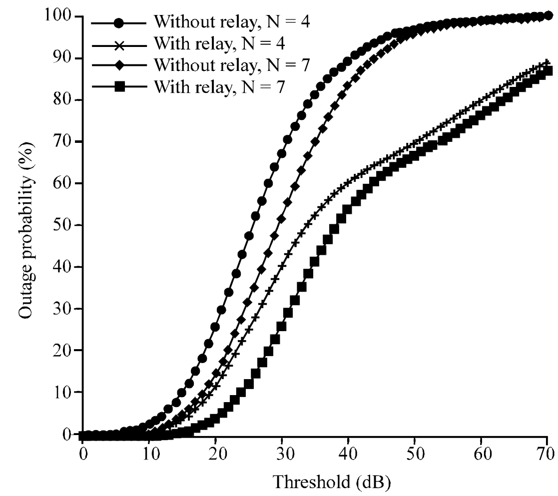

Fig. 7: Outage probability at different thresholds with relays of 120° directional antenna

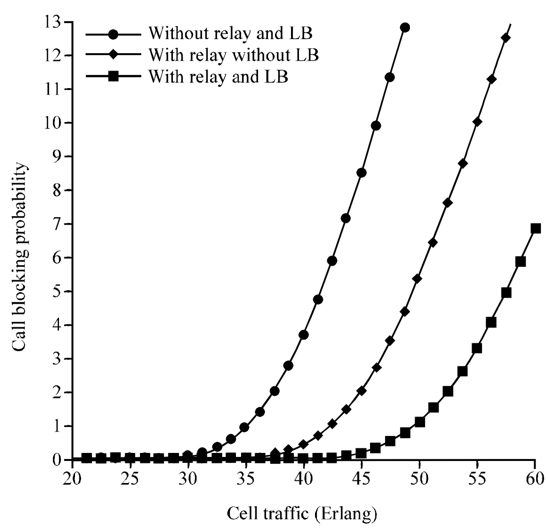

Fig. 8: Relationship between blocking probability and cell traffic for cluster size of 7

variation with distance calculated at mobile station for cluster size equal to 7. Figure 3 shows that there is a noticeable enhancement in the coverage. Figure 4 shows that the relays with 120° sector directional antenna can improve received power.

Relay with sector coverage transmitting signal just in the gap direction and this can gives better ratio of SIR. Figure 5 and 6 show the variation of signal to interference ratio SIR with distance for two cluster size (4 and 7) and two relay's antenna types (Omni directional and sector).

The sectorized antenna gives better coverage improvement when the relay position is probably selected.

Figure 7 shows the average outage probabilities at different thresholds for cluster size (4 and 7) with and without relays which gives lower outage probability by using relay with 120° sector coverage.

The impact of load balance is examined in Fig. 8. An improvement in blocking probability occurs by using relays, this improvement can be optimized and enhanced by using load balance.

Figure 9 shows the call blocking probability with different number of users. Results show that using relay can increase the number of users when relay and load balance are used. One of the important parameters of performance in cellular network is the spectral efficiency.

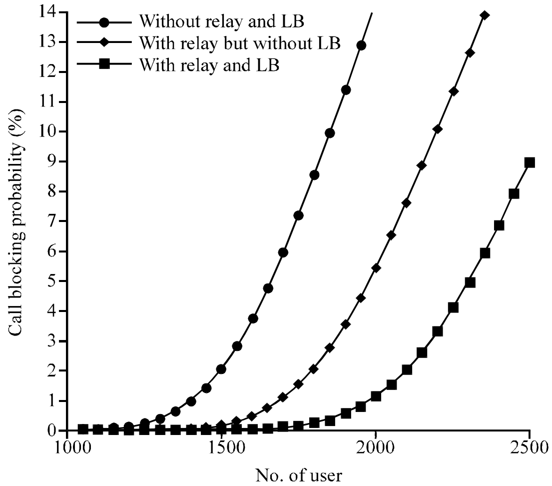

Fig. 9: Relationship between blocking probability and number of user for cluster size of 7

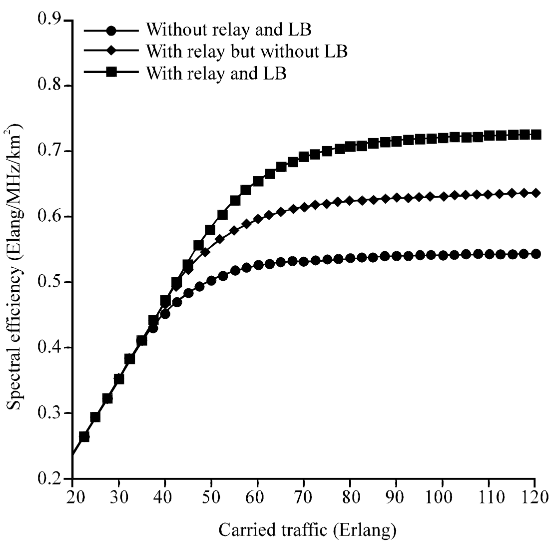

Fig. 10: Cell spectral efficiency and carried traffic for cluster size is equal to 7

Figure 10 shows that when carried traffic is <40 Erlang, spectral efficiency is approximately the same for the three scenarios. This happens because cells do not have blocking probability problem but in the case when carrying traffic above this value spectral efficiency improves with using relays and load balance.

CONCLUSION

In this study, researchers have presented a new model for coverage and capacity enhancement by using digital relays and load balance. By using the proposed model, they can eliminate dead zones to get full coverage. The simulation results show that adding relays can produce better cellular coverage with lower system outage probability. In addition to coverage improvement relays can also be used to enhance cellular capacity and performance by reducing blocking probability.

Furthermore, enhanced system capacity can produce larger carried traffic by the same resources and the same cell area, leading to better spectral efficiency of the network.

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