Capacity and Coverage Increase with Repeaters in UMTS

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Abstract: Due to the limitations of the radio wave propagation, there are possibilities of having zones in the mobile communication system where the direct signal from the base station does not reach the Mobile Station. These zones are conventionally called "dead zones" such as tunnels, shopping malls and other indoor venues. Repeaters are the most effective and an efficient way to provide the mobile service guarantee from both operator and user point of view. Besides that, operators use repeater to extend network coverage, which leads to a capacity cut off due to the repeater noise. We proposed to consider repeater to increase capacity for urban areas where path loss exponent is more than 3.4. In this paper we analyze the system capacity and coverage for both uplink and downlink with the 3GPP recommended repeater.

Keywords: Universal Mobile Telecommunication System (UMTS), Quality of Service (QoS).

1. Introduction

In UMTS cells are designed with a layered structure e.g. picocell, microcell, macrocell. The available radio resources also vary from layer to layer but remain the same QoSs demanded[1]. One of the benefits of UMTS is improved and continuous QoS guarantee with extended capacity and coverage compared to the existing systems such as GSM. Even in regions with sufficient link budget, due to the terrain variety and the dense urban structure there are places that cannot have as good coverage as the network is designed. From a QoS perspective, the call dropping is more problematic than call blocking.

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One of the most cost effective engineering solutions for this situation is to insert a repeater [2][3], which may incur only 15-20% of cost of a new base station. It is expected that the insertion of repeater reduces the capacity of the system [4]. Repeaters are usually used to extend the coverage in rural and suburban environments. We proposed to insert repeater in dense urban areas to increase the coverage as well as system capacity. We analyze the network coverage and capacity with and without repeater in different propagation condition. Our simulation shows that

1. The CDMA system capacity with repeater is the trade off with coverage, up to the path loss exponent of 3.4.

2. Beyond this point, presences of repeaters provide the system capacity and the coverage increment.

3. Doubled System capacity can be achieved by inserting repeaters to extend the coverage in the propagation environment with the exponent of in between 3.7- 3.8 for ITU pedestrian A channel and in between 3.8 – 3.9 for ITU Vehicular A channel.

Even if the operators use the repeater to extend or improve the coverage, the total interference reduces due to the reduction of intercell interference. This reduction is due to the increase of the cell coverage radius, which leads to a capacity improvement. In the following section of the paper we introduce a system model in section 2, clarify the effect of repeater on system capacity in section 3, we examine the extension of coverage scenarios with repeater in section 4, finally the conclusion in section 5.

2. System Model

For our simulation model we considered a 7-cell cluster and the central cell serves the test mobile. Mobiles within the network are uniformly distributed and there are regular grids of Base station [1]. To increase the coverage 3 repeaters are placed in every cell in such a way that the coverage radius in the direction of the side-lobe in every sector becomes approximately equal to the coverage radius in the direction of the main lobe radiation. In doing so repeaters are placed in between the side-lobe radiation edge of two-neighbor sector of the parent cell (Fig 1(b)). All three repeaters are 120^0 apart from each other and 60^0 apart from the center of the base station sector main such a way that the signal around the extended radius within the cell is easy to reach. Repeaters are selected such a way that the downlink sensitivity level of the repeater donor antenna is equal to the sensitivity level of user equipment and for uplink repeater antenna sensitivity level is the same as the base station antenna sensitivity level. Repeater uplink amplifier gain is 5dB greater than that of downlink. (These assumptions are made from the repeater specification from the manufacturer)[5]. We also consider the terrain is uniform.

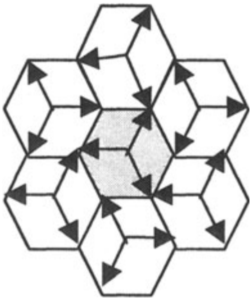

Fig: 1(a) - hexagonal cell geometry with 7 cell cluster

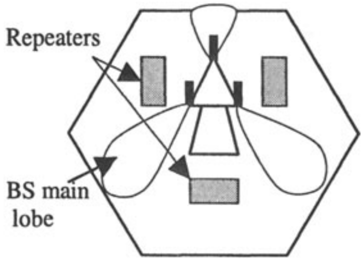

Fig:1(b) - Single cell with three sectors and three Repeaters

3. Effect of repeater on system capacity

For our simulation we have used following data in both uplink and downlink.

Downlink	
BS transmit power	40 dBm
BS antenna gain	15dB
Repeater donor antenna gain	20dB
Feeder loss	4dB
Sensitivity level of Repeater donor antenna	-70dBm
DL frequency	2140MHz
DL amplifier gain	87dB
MS sensitivity level	-70dBm
Fading margin	10 dB
BS noise figure	5dB
Repeater Noise figure	3dB

Bit rate	12.2^{*}, 144^{**}, 384^{***} kbps
Target SNR	5dB^{*}, 1.5dB^{**}, 1.0dB^{***}
UPLINK	
MS transmit power	24dBm
MS antenna gain	0dB
Repeater Uplink amplifier gain	92dB
BS sensitivity level	-96dB
Repeater antenna UL sensitivity level	-96dB
UL frequency	1950 MHz
Test Mobile distance	200m
Chip rate	3.84 Mcps
VAF	0.4

the target Eb/No of downlink radio link for any specific service can be determined by the following equation from [5]:

$$\left(\frac{E_b}{N_0}\right)_{target} = \frac{\frac{W \cdot P_t}{L_m}}{R \cdot N} \quad ...(1)$$

Where W is chip rate, P_t is the transmitted power at the Base station for specific service radio link, R is bit rate, L_m is path loss between the serving base station and test mobile, N is total interference and noise.

$$N = N_{th} + NF_{BS} + (NF_{rep})^* + I \text{ ....(2)}$$

where N_{th}, NF_{BS} and NF_{rep} are thermal noise, base station noise figure and repeater noise figure respectively. Note that the repeater noise (*) will be added only when the system is considered with repeater.

$$I = P(X+Y)\text{....(3)}$$

Where $X = \frac{(1-\alpha)}{L_m}$ and $Y = \Sigma \frac{1}{L_n}$

P is the budgeted transmit power from the base station. X is the same cell interference and Y is the other cell interference, in our simulation we considered only cells within the active set, α is orthogonality factor (orthogonality factor is the uniqueness of the transmitted signal from each base station) which is 90% for ITU Pedestrian A and 60% for ITU Vehicular A, (α is 100% for a single propagation path, we assume another 10% decrement in orthogonality factor when the system with repeater has considered), and L_n the path loss from the neighbor base stations within the active set to the test mobile. For simplicity, we can rewrite the equation (2) as follows:

$N = N' + I$ ....(4) Where $N' = N_{th} + NF_{BS} + (NF_{rep})^*$

From equation (1) it can be determined the power required to maintain a radio link for a specific service as the following equation:

$$P_t = \left(\frac{E_b}{N_0}\right)_{target} \cdot \frac{R}{W} \cdot \left[L_m \cdot N\right]\text{.....(5)}$$

Substituting the value of N from equation (2), (3) and (4) in equation (5) it can be rewritten as follows:

$$P_t = \left(\frac{E_b}{N_0}\right)_{target} \cdot \frac{R}{W} \cdot \left[P((1-\alpha)+Y \cdot L_m)+L_m \cdot N'\right]\text{...(6)}$$

Since it is very difficult to define the location mobile within a practical network, hence we introduce a factor x that will be use to calculate the average instantaneous distance of any mobile in the network. Average distance of any mobile from other neighbor base station in the active set (we consider no of cells in active set are 6 as recommended for UE in [9]) is approximately equal to the distance between two base stations if they are placed in uniform grid in the network and if we consider serving cell is in the center of the 7 cell cluster and rest 6 are the members of active set. The value of x have been according the above assumption as the following table where n is the propagation constant:

n	x
2.0	0.850
2..5	0.825
3.0	0.800
3.5	0.775
4.0	0.750
4.5	0.725
5.0	0.700

From the above assumption the value of L_m.Y of equation (5) can be determined with the relation

$Y \cdot L_m = Z \cdot \left(\frac{d}{D}\right)^n \cdot \frac{1}{x}$ ...(7) where Z is the number of cell within the active set.

Also in equation (7) d is the distance of the test mobile from the serving base station and D is the distance between two base station in uniform grid network and Z is the no of cells within the active set . If we consider the transmit power budget is constant from every base station then with that amount of power total number of radio link can be supported can be find from the following relation where VAF is the Voice Activity Factor.

$$No\_of\_Radio\_link = \frac{P}{VAF \cdot P_t} \quad ....(8)$$

In our system model repeaters are inserted in such a way that there is a probability of hearing maximum of six nearest base through the repeaters. This signal strength gives an additional increment in I (In eq. 3). On the other hand, the insertion of repeaters [with the parameters used in our system model] allowed for an increase in the distance of 60-80% in different environments, which allows a significant decrement in I. Besides that due to the additional path through the repeater (for the user under the repeater coverage i.e. if the test mobile with this region), the orthogonality factor α reduces considerably. The capacity of the system model has been measured for different bit rate in terms of number of radio link service capability. Simulation results are given below.

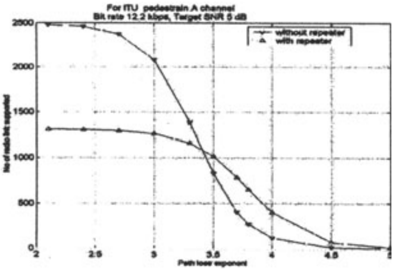

Fig 2: (a)

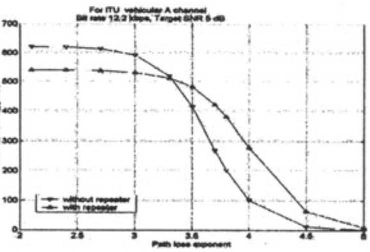

Fig 2: (b)

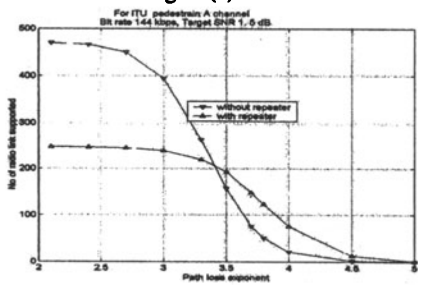

Fig 2: (c)

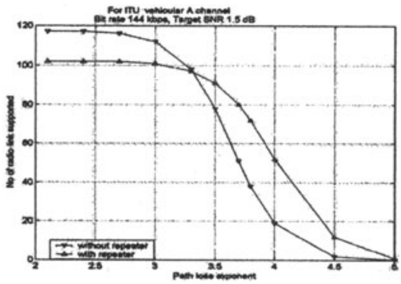

Fig 2 - (d)

Our simulation shows that for ITU Pedestrian A channel the repeaters within the environment of path loss exponent 2 – 3.4 (2-3.3 for ITU Vehicular A channel) increase coverage with trade off of no of radio link capacity. But within the region with this path loss exponent operators are thinking to minimize coverage cost as there are lower numbers of users within this region and which cannot make them to compensate the network installation cost. On the other hand beyond the path loss exponent of 3.4 the system capacity of the network with repeater starts to dominate the capacity of the network without repeater.

A doubled system capacity can be obtained for the path loss exponent in between 3.7 – 3.8 for ITU pedestrian A channel and for ITU Vehicular A channel it is in between 3.8-3.9, which is very common in dense urban area. This gain is comes due to the capability of making possible the base stations considerably apart from each other and thus reducing intercell interference significantly. This lowered interference allows the equipments to reach their target SNR with a low power requirement from the base station to maintain the radio link. Hence with the same budgeted transmit power from the base station able to more radio link than that of the system with out repeater. From the result shown above it could be conclude that for rural and suburban areas where path loss exponent is low and coverage is most considerable issue, repeater can give significant solution. On the other hand for urban areas where path loss exponent is high, repeater can dominate the capacity of the network without repeater as well as the coverage significantly. It should be noted that even though we have considered a 7 cell hexagonal cluster, the behavior of the number link supported with respect to path loss exponent will remain same regardless of the cell geometry if the network with repeater designed such a way the extended radius uniform in each direction.

4. Extension of coverage with repeater

The coverage extension is dependent on the repeater coverage antenna gain, the donor antenna gain and the repeater amplifier gain. In our system model we consider three sectors per cell each 120-degree. With ideal directive property in sector antenna, signal attenuation is lower towards the direction of the main lobe than that of the side lobe. So we proposed to install repeater in intracell hand off region i. e 60^0 apart from the main lobe center. Due to the additional noise in

the repeater amplifier the repeater should not inserted just along the cell boundary [2]. This threshold is the function of the repeater noise figure. Usually the coverage is the most important issue of consideration while designing the network for the rural and suburban areas where the path loss exponent is lower than that of the urban areas. To overcome this coverage problem we investigated the performance of the repeater. The most effective positioning of the repeater when it is intended to extend the coverage is in between the sector boundary (in intra cell hand over region) and within the coverage threshold of the base station. We performed our simulation for different environment. In our simulation we have used the assumed data in the table I.

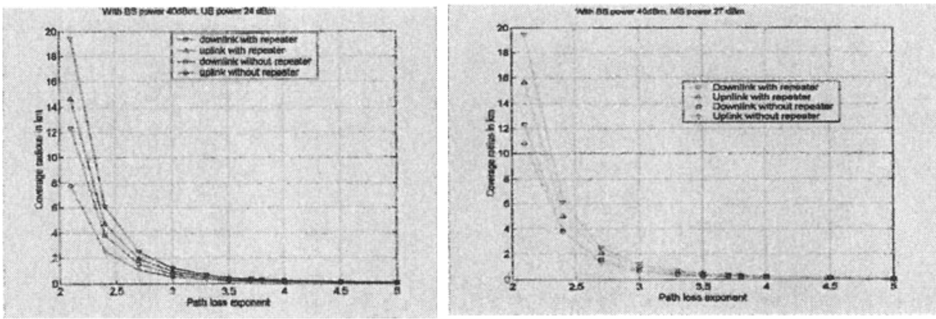

Fig 3: (a) Coverage comparison in different environment

Fig 3: (b) coverage comparison in different environment

Our simulation shows that the extension of coverage with the repeater is more efficient in rural and suburban areas than that of the urban area. The coverage radius can be extended 60-80% in different area but doing that there is a cut off in the capacity of about 20-50%. This cut off in capacity is found due to the repeater noise. However, statically within these environment operators are concern about coverage and available capacity could be enough to serve the existing user. A base station and three sets of duplex repeater can serve a coverage for which at least three base stations is to be installed.

5. Conclusion

In this paper we analyzed both the system capacity and the coverage in UMTS environment where fast power control has been adopted in both the uplink and the downlink. From the simulation results it could to be conclude that the repeater, which is usually used in extension of coverage could be used to increase the system capacity as well as the coverage in dense urban area. Due to the dynamic control in each radio link power of different service and environment to meet the target SNR, it is possible to design UMTS network with repeater and control the repeater with the algorithm that have been proposed in [3] which will help to optimize the capacity cut off in rural and suburban areas. In our future work we are targeting adaptive SDMA possibility with repeater for layered structured UMTS network.

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