Using Remaining Battery lifetime information and Relaying to decrease Outage Probability of a Mobile Terminal[1]

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Abstract—**The aim of this paper is to demonstrate that by employing relaying and using the remaining battery lifetime information of Mobile Terminals (MT) in next generation cellular networks, the outage probability of the MT is reduced. We define outage probability as the probability that the connection between the MT and the Base Station (BS) is lost when the MT is asked to use a transmission power greater than some threshold. This threshold is determined based on the remaining battery lifetime of the MT. We assume a linear relationship between the remaining battery lifetime and the maximum allowed transmission power. We used a 2-hop relaying mechanism to illustrate our concept, and simulated for both urban and sub-urban terrains. We will see that outage probability is significantly different for both the terrains, upon which we suggest the type of relay suitable for relaying for each of the terrains. We consider two types of relays - relays which have infinite battery power like for cars, and relays which have finite battery power like for other MTs.**

Keywords-Next Generation Cellular Networks, Relaying, CDMA Systems, Remaining Battery Lifetime information, Outage Probability.

I. INTRODUCTION

The required transmission power of the MT is dependent mainly on the distance and fading encountered between the MT and the BS, and is strictly controlled by the BS using closed-loop power control. Closed loop power control, while controlling the transmission power of the MT does not take into consideration the remaining battery life of a mobile terminal. Therefore, it is possible that a mobile with low battery power is asked to transmit at higher levels, because it is farther away from the BS, or it is in a dead zone, resulting in an outage. By using relaying, the propagation distance required for the MT to transmit is reduced, and therefore the probability that it will exceed its maximum transmit power is reduced. We show that by combining relaying with remaining battery life information, the outage for MTs with low battery power is reduced, which translates to longer lifetime of the battery.

In this paper, we use a 2-hop relaying mechanism, as described in [1] and [2], where relays can be devices which have an infinite power reserve like cars, and even MTs, which have sufficient battery lifetime. Having a 2-hop connection instead of a multi-hop connection will guarantee a bounded delay, unlike multi-hop relaying mechanisms like Opportunity Driven Multiple Access [3]. The routing protocol is also simple, which reduces the overhead at both MTs and relays [2]. We have used the link budget of CDMA based cellular networks. [2] explores how relaying can be implemented in 3G cellular networks.

In this paper, we make the following assumptions.

- We assume a linear relationship between the remaining battery lifetime and maximum transmission power of the MT.
- The MT will transmit its remaining battery life information to the BS, from which the BS can calculate the maximum transmission power for the MT. Currently chipsets which can measure the remaining battery capacity are available in the market [4].
- The BS knows the location of the relays and the MT. In the future, GPS would be a part of every wireless device, using which the BS could determine their exact location and approximate path loss between MT, relays and BS.
- The BS will know the transmission power of the MT, either by calculating it, or the MT will inform the BS using control channels.
- The BS will choose a relayed connection for a MT only if the cumulative transmission power to the BS via the relay is lesser than the direct transmission power to BS.
- Based on the received signal levels at the relay the BS, which knows the location of all the relays and MTs, does a global optimization to find the best relays for each MT. With just 2-hop relaying a simple assignment algorithm at the BS suffices.

Relays like cars can have infinite battery power, while relays like other MTs can have finite battery power. This is factored into our simulation, and is defined in section II. We consider both urban and suburban terrains in our simulation, and their link budget and simulation methodology is described in section III. Section IV, provides detailed analysis of the

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simulation results, while Section V suggests the type of relays suitable for suburban and urban environments.

II. RELAY SELECTION MECHANISMS

In this paper, we distinguish two types of relays – relays with infinite battery lifetime, i.e., the elapsed lifetime of the relay's battery is considered zero, and relays with finite remaining battery lifetime, i.e., the elapsed lifetime of the battery, is finite. For example, the latter can be other MTs, and the former can be cars, which have infinite power reserve, and therefore an infinite battery lifetime.

The sum of the transmission power required for MT-relay and Relay-BS arms of a relayed can be lower than that of a direct transmission to BS. More than one relay may satisfy this condition, and therefore, multiple relays are eligible for relaying for the MT. The factors that determine choosing the relays are the remaining battery lifetime of the MT, the elapsed battery lifetime of the relay, and transmission powers required for both MT and relay. The cost of relaying is sum of the cost for MT to transmit to the relay, and the cost for the relay to transmit to the BS. Since the remaining battery lifetime and the required transmit powers are independent input parameters, the cost of a connection is the product of remaining battery lifetime and transmit power. For a 2-hop relayed connection, the general formula for the cost of a relayed connection is given by,

$$Cost(R) = R_m * T_{mr} + E_r * T_r \tag{1}$$

where,

R_m is normalized remaining battery life of MT

T_{mr} is required transmission power to a relay in watts

E_r is normalized elapsed battery life of a relay

T_r is required transmission power to the BS from relay in watts

In our simulation, a lower cost value given by (1) is desired. Since we want to choose relays with higher remaining battery lifetimes to relay calls, having remaining battery lifetime in the equation will contradict the meaning of the cost equation. Therefore, we choose elapsed lifetime of the relay.

The cost of transmitting directly to the BS is given by

$$Cost(D) = R_m * T_{md} \tag{2}$$

where, T_{md} is the required transmission power in watts for a direct connection from MT to BS. The costs of both direct and relayed connections are calculated by the BS, which then does an optimization for the entire cell to find out best MT-relay pairs. While finding MT-relay pairs, the BS the following constraints are made.

1. $$T_{mr} + T_r \leq T_{md} \tag{3}$$

This constraint is necessary in case the relays are other MTs. Since the energy expended by the MT is valuable, this constraint ensures that the relayed connection consumes lower energy than the direct connection. For the case of relays with infinite battery lifetime, T_r is neglected. The relation then reduces to

$$T_{mr} \leq T_{md} \tag{4}$$

2. $$R_m > E_r \tag{5}$$

This constraint ensures that an MT is not draining the battery of relays with a lower battery lifetime than its own. This condition is always true for relays with infinite battery lifetime.

3. The MT with least remaining battery lifetime gets to choose the relay first, so that the outage probability can be reduced.

Constraint #3 is implemented by arranging the MTs in ascending order of their remaining battery lifetime and then choosing relays for them.

The general condition for choosing the relay is given by

$$Cost(R) < Cost(D) \tag{6}$$

When relays are cars, E_r = 0, and therefore, the cost for relayed connection becomes

$$Cost(R) = R_m * T_{mr} \tag{7}$$

The condition for choosing the relay reduces to (4). In case the relays are other MTs, E_r are non-zero, and the condition for choosing the relay is given by expanding (6)

$$R_m * T_{mr} + E_r * T_r < R_m * T_{md} \tag{8}$$

The MT chooses a relay with lowest $Cost(R)$ as given in (1). After an MT chooses the relay, that relay is no longer available for remaining MTs, as we assume that a relay can handle only one MT at a time. In this paper, we assume that the remaining battery lifetime, R_m, and the Elapsed battery lifetime E_r, are random numbers between 0 and 1, with a uniform distribution. Assuming a linear relationship between remaining/elapsed battery lifetime and maximum allowed transmission power, the value for the latter is given by

$$T_m = R_m * T \tag{9}$$

where, T is the Maximum Transmit power in watts given in Table 1. The relationship between T_m and R_m is illustrated in Fig 1.Outage for the MT is calculated by comparing the transmit power T_{mr} required to transmit to its chosen relay and the MT's maximum transmit power T_m. If T_{mr} is greater than T_m, an outage occurs.

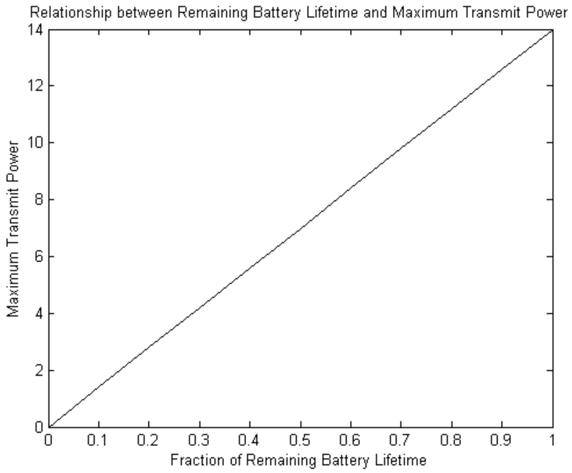

Figure 1. Relationship between Remaining Battery Lifetime and Maximum Transmit Power in Urban Environment

TABLE I. SIMULATION PARAMETERS

Parameters	Urban	Suburban
Grid Size	20m	200m
Node Velocity	1m/s	33.33m/s
E_b/N_0 (E)	3.3dB	5dB
Bandwidth (W)	5Mhz	5Mhz
Data Rate(I)	8000	8000
Receiver Sensitivity(R)	-126.7dB	-125dB
Maximum allowable path loss	142.4 dB	157.7dB
Cell Antenna Gain (G)	10 dB	13 dB
Standard Deviation of Propagation loss	10dB	10dB
LogNormal Fade Margin (L)	11.3 dB	11.3dB
Cable Loss (C)	2dB	2dB
Handoff Gain (H)	5dB	5dB
Processing Gain (PG)	27.95dB	27.95
Maximum Transmit Power (T)	14dBm	28dBm
Antenna Height Difference(h)	0	15

III. SIMULATIONS

We used a combination of discrete event based simulator, described in [1] and Monte Carlo simulations using MATLAB for the measurements for a single-cell. The terrain is divided into grids, with sizes of 20m and 200m for urban and suburban environments respectively. Obstructions are regularly placed with the terrain. The nodes and relays are always moving at velocities of 1m/s (3.6km/hr) and 33.33m/s (120km/hr) in urban and suburban environments respectively. The nodes are always in active mode, while the relays are dedicated only for relaying. The cell antenna gain is only included for the connection between MT and BS and between relay and BS. It is not included for the connection between MT and relay because the relay receiver is assumed a simple one, without any directional antennas or Multi User Detection mechanisms. We ensured that when the MTs in both urban and suburban terrains use their maximum transmit power, there is zero outage.

Four scenarios are simulated.

1. Urban test environment with infinite battery lifetime of relay. Therefore the constraint related to this scenario is given by (4), while (5) is always true. The cost equation is (4).
2. Urban test environment with finite battery lifetime of relay. The constraints related to this scenario are (3) and (5) and the cost equation is (8).
3. Suburban test environment with infinite battery lifetime of relay. Therefore the constraint related to this scenario is given by (4), while (5) is always true. The cost equation is (4).
4. Suburban test environment with finite battery lifetime of relay. The constraints related to this scenario are (3) and (4) and the cost equation is (8).

The link budget parameters used for these four scenarios are shown in Table 1, and the formula for calculating the transmission power based on path loss between the MT and either the relay or BS is given in (10). The path loss for urban terrain is calculated using the Recursive path loss model for a Manhattan test environment, while the path loss for suburban terrain is calculated using the vehicular test environment [5].

The transmission power is calculated using the following formula [5].

$$\text{Transmit Power } (Pt_0 \text{ in dB}) = -(N_0 W) - PG + E + L - G - H + C + \text{PathLoss(dB)} \qquad (10)$$

For each of the scenarios, MT with lowest remaining battery lifetime is given preference. The remaining battery lifetimes and elapsed battery lifetimes of MT and relay respectively are uniform random numbers between 0 and 1, obtained with different seeds. The MTs and relay locations are sampled every 5 seconds, which becomes a snapshot. 800 such snapshots are taken, and applying the relations of Section II, the outage is calculated for both direct connection and for the relayed connection. The number of relays is varied, and Outage is calculated.

IV. RESULTS

The results from the four scenarios in our simulation are shown in Fig 2 and 3. Fig.2 shows the results for urban environments of scenario 1 and 2, while Fig.3 shows the results for suburban environments of scenario 3 and 4. The x-axis is the number of relays, and y-axis is the ratio of the outage probability for a relayed connection and the outage probability of the direct connection.

The first observation that can be made by comparing the two figures is that the outage in suburban terrain reduces only with large number of relays, while outage reduces significantly even with fewer number of relays in urban terrain. The reason for higher outage in suburban terrain is due to the difference in antenna heights of the Base Station and the relay. We assume a zero height difference between the antennas of relay and MT, while a 15m height difference between antenna heights of both relays and MT with the BS [5]. The variation in path loss with antenna height for a suburban terrain is shown in Fig 4. The

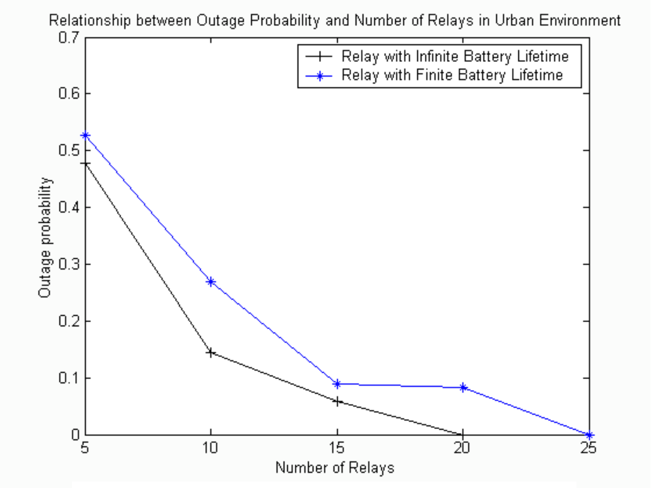

Figure 2. Outage probability in Urban Environment

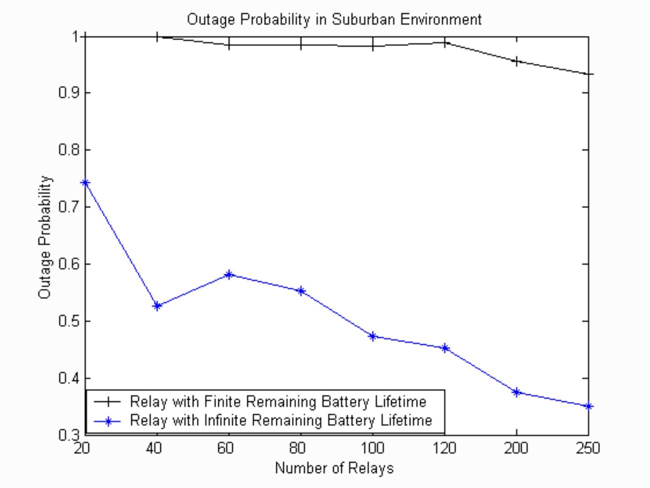

Figure 3. Outage probability in Suburban Environment

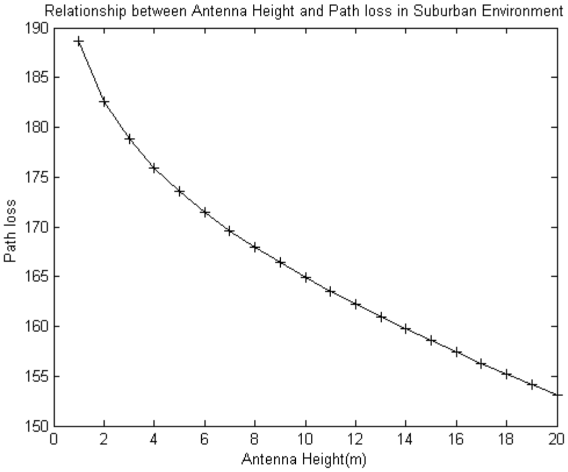

Figure 4. Effect of Antenna Height on Path loss in Suburban environment

physical distance between the source and destination is 1000m. We can observe from the plot that path loss is approximately 30dB less when antenna height difference is 15m when compared to a zero antenna height difference. Moreover, we are not assuming any cell antenna gain for the relay, and therefore, the cumulative loss is approximately 40dB when relaying is employed. Therefore, the MT will have to find relays, which are very near to them to overcome this loss. Only when the number of relays in the cell are large and relays have infinite battery lifetime (Scenario #3), will the probability of the MT finding nearer relays increase, and therefore the outage probability can decrease.

In urban terrains, only the propagation distance is the significant factor in determining the path loss, and therefore, outage is reduced when relays are physically present between BS and MT. Therefore bigger decrease in outage probability is achievable as a function of number of relays, as shown in Fig 2. Even a few relays are sufficient to gain a zero outage probability.

Another observation from both Fig.2 and Fig. 3 is that the outage probability is lower when the relays have infinite battery lifetime, since all the relays are candidate relays. But for scenarios 2 and 4, where relays have finite battery lifetime, the number of candidate relays are limited, and therefore the outage probability is higher.

From Fig. 3, we see that the outage probability is surprisingly high for Scenario 4. This behavior can be attributed to propagation environment. In order to increase the outage probability for the latter case, we relaxed constraint #1 by using (4) instead of (3), and removing constraint #2. Fig.5 shows the effect of this change. Here, we do not care if the relay is farther away from the BS than the MT is, and also if the relay has lower remaining battery life than the MT.

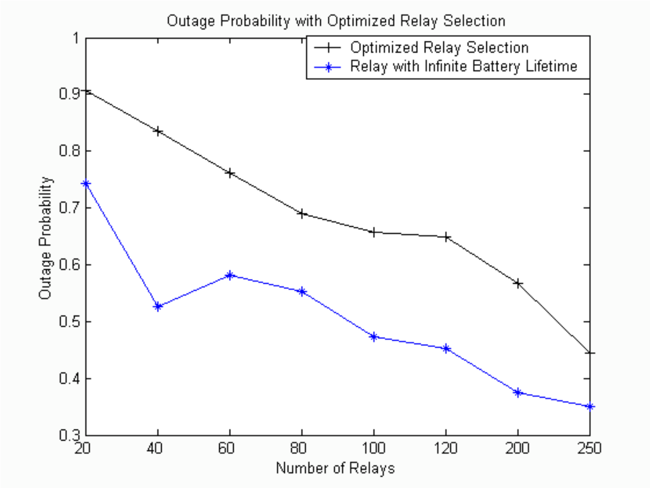

Figure 5: Outage probability in Suburban environment using (4)

V. CHOICE OF A RELAY

We observed from Section IV, that in urban terrain, very few relays are sufficient to obtain an outage probability of zero. In suburban terrain, only those MT-relay pairs, which are very close to each other, can overcome the propagation loss caused by zero antenna height difference between relay and MT. In a suburban setting, a velocity of 120km/hr (33.33m/s) is achievable only while traveling. If we make the vehicle the user is traveling in as the relay, each MT can have a dedicated relay with infinite battery life, and outage probability can be zeroed out. Alternatively, instead of having relays, we can install repeaters, with antenna height comparable to that of the BS, to reduce outage probability. In urban areas, where micro cells are installed, other MTs as relays can be used instead of making micro-cells smaller to reduce the outage probability. Since only a few relays are sufficient to reduce outage, a 2-hop relaying can substitute for expensive infrastructure costs.

VI. CONCLUSION

In this paper, we have defined outage probability as the loss of a connection when the MT's transmit power exceeds its maximum transmit power. We saw that outage probability is reduced when we combine the remaining battery life information with relaying. Both urban and suburban terrains were considered, and we saw that relaying reduces outage probability to zero in urban terrains, while in suburban terrains, the outage probability was non-zero. Relays with infinite battery lifetime provide lower outage probability, while relays like other MTs with finite battery lifetime provide higher outage probability.

VII. REFERENCES

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