Analyzing the Application of Inter-cell Relay in CDMA Cellular Networks

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Abstract

Multihop communication has been proposed in cellular networks to overcome some inherent limitations. Congestion relief and load balancing are amongst the promised gains. In this paper, we investigate inter-cell relay - which means diverting calls from one congested (heavy loaded) cell to an adjacent less loaded cell for congestion relief (load balancing) - in multihop CDMA cellular networks. The application of inter-cell relay changes the resulting interference inside the heavy loaded cell as well as at the supporting BSs. Toward analyzing the gains from inter-cell relay, we derive formulas for interference experienced at the congested and supporting BSs. Upper bound on number of calls supported inside the area of the congested cell is derived based on interference formulas. We show that inter-cell relay can increase the number of accepted calls inside a congested cell.

1. Introduction

Third Generation (3G) wireless networks have adopted Wideband Code Division Multiple Access (WCDMA) technology. Despite the advances achieved in 3G, cellular networks will still suffer inherent limitations on capacity and coverage. WCDMA-based networks are interference limited, which means that their capacities are affected by usage, positions and mobility of users. Various proposals have been made to overcome this limitation including enhanced functionalities for Radio Resource Management (RRM) overseeing admission [1] and power control [2].

However, a solution that has been gaining prominent attention is that of exploiting the advances made in the area of multihop wireless relay. Accordingly, multihop communication has been proposed to be added on top of cellular infrastructure, in what is known as Multihop Cellular Networks (MCNs), to overcome drawbacks like congestion, load imbalance and dead spots [3].

Some efforts have been devoted toward investigating the different aspects of MCNs. Different proposals have been suggested in the literature [4] – [6]. Other works attended to the operational requirements of MCNs, like channel assignment and resource utilization [7], [8].

In our previous work, we showed that using multihop communication in CDMA cellular networks can increase network capacity [9] and reduce consumed energy [10]. In this paper, we investigate the potential gains achieved by inter-cell relay in CDMA-based MCNs. Inter-cell relay means relaying calls originating in one heavy loaded cell to Base Stations (BSs) of adjacent less loaded cells for the purpose of congestion relief or load balancing. Load usually varies among cells resulting in load imbalance, which can result in unfair rate allocation between different users. Users in heavy loaded cells are usually allocated lower rates than users in less loaded cells. In addition, congestion can occur in one cell, even if free resources are available in adjacent cells. In traditional single-hop cellular networks, calls in congested cell cannot use available resources in adjacent cells. Using inter-cell relay in MCNs, load balancing and congestion relief can be achieved.

Toward analyzing inter-cell relay in CDMA-based MCNs and since CDMA-based networks are interference limited, we derive formulas to quantify interference when applying inter-cell relay. To guarantee the quality of all calls, interference has to be calculated at heavy loaded BS as well as BSs where calls are relayed. Using the interference formulas, upper bound on number of calls is determined. We show that the number of accepted calls can be increased inside a congested cell using inter-cell relay.

The remainder of the paper is organised as follows. In section 2, the models used in the analysis are introduced. In section 3, inter-cell relay analysis is presented. Formulas, to quantify interference when inter-cell relay is applied, are derived. Section 4 demonstrates numerical results. Section 5 concludes the paper.

2. System Model

We adopt a multi-hop CDMA cellular network model similar to that in [9]. Cells are hexagonal, with each cell neighboring six other cells. Cells are divided into k co-centric discs with equal widths centered at BSs. Discs are numbered 0 to k - 1 in an ascending order with the inner-most disc being disc 0. An example cell with four discs is shown in Figure 1. The case with one disc represents the single-hop case.

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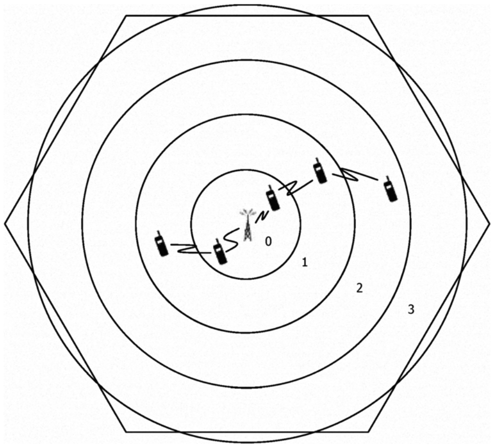

Figure 1. A cell with 4 discs

We consider an uplink slot. Only mobile terminals (MTs) inside the inner-most disc are allowed to communicate directly with BS. MTs in outer discs relay data through MTs in next disc closer to BS. We adopt a generic model that can be used in time division duplex (TDD) or frequency division duplex (FDD). Hence results are considered to be per time slot per frequency band. Calculations are done on circular cells, which is a good approximation [11]. All MTs and BSs use omni-directional antennas.

In analysis, we consider a 19-cell cluster. To simplify the discussion, and without loss of generality, we adopt the following tagging convention. We define a target cell, which is the cell in the center of the cluster. This is the main cell in the analysis. Cells, which are adjacent to the target cell, are called 1st tier (B1) cells. Cells, which are adjacent to B1 cells but not the target cell, are called 2nd tier (B2) cells. A target cell, its 1st tier (B1) cells and 2nd tier (B2) cells are shown in Figure 2. The number of calls in target cell, B1 cell and B2 cell are denoted N_{Tg}, N_{B1} and N_{B2}, respectively.

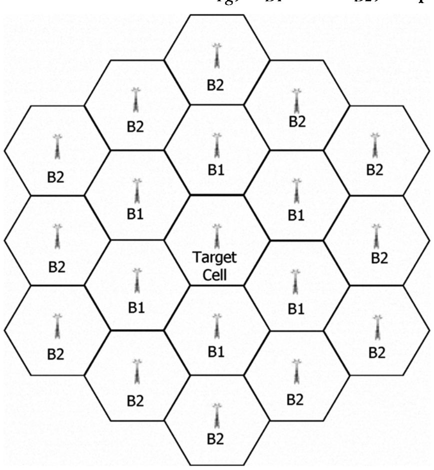

Figure 2. Layout of cells used in analysis

In order to perform interference analysis, a signal propagation model has to be identified. We use the lognormal attenuation model, which is widely accepted in the analysis of CDMA-based networks [12]. In this model, the power of a received signal can be given by

$$S_r = S_{tr} d^{-m} 10^{\xi/10} \quad (1)$$

where S_{tr} is the transmission power, d is the distance from transmitter to receiver and ξ represents shadowing effects. m is the path-loss. Variable ξ is normally distributed with zero mean and a standard deviation σ. Shadowing effect does not depend on distance travelled by signal and is usually estimated using expectation. Accordingly, shadowing effects are ignored in the analysis.

3. Inter-Cell Relay Analysis

In traditional single-hop cellular networks, calls originating inside one cell cannot utilize available resources in an adjacent cell. When a congested (heavy loaded) cell is adjacent to a lightly loaded cell, it could be beneficial to let calls inside congested (heavy loaded) cell use the available resources in the lightly loaded cell. In MCNs, inter-cell relay can divert calls from one congested (heavy loaded) cell to an adjacent cell for congestion relief (load balancing). In order to evaluate the gains of inter-cell relay, the potential increase in capacity has to be quantified. Capacity of CDMA-based networks depends mainly on interference. Hence, we derive equations to quantify the resulting interference when inter-cell relay is applied. We assume that calls are inter-cell relayed from the target cell to B1 BSs (Layout in Figure 2). Inter-cell relay changes the resulting interference. Hence interference has to be calculated at the BS of the target cell as well as at the supporting B1 BSs.

3.1. Relaying and Non-Relaying Areas

A scheme, that determines which calls to be inter-cell relayed, needs to be devised. A logical choice will be calls from MTs close to cell borders. For instance, MTs are considered close enough to cell border that their calls can be relayed to adjacent BSs, if they are in the transmission range of MTs inside the area of an adjacent cell (other relay schemes can also be considered, and similar calculations to what follows can be derived). The distance between these MTs and the supporting BS has to be less than $D + r_0$, where D is the cell radius and r_0 is the radius of the innermost disc and the transmission range of MTs. These MTs with relayed calls are naturally inside the area of the target cell and outside the cell area of supporting BS. Therefore, MTs, that lie inside the intersection area between the target cell and a disc centered at a supporting BS with inner disc D and outer disc $D + r_0$, can relay their calls to adjacent BSs. This intersection area is referred to as the relaying area. The rest of the target cell is the non-relaying area.

In the analysis, the target cell is divided into six sectors each with an angle of pi/3 degrees. Each sector is divided into a relaying area and a non-relaying area. Dividing into sectors eases the condition for integrating over the non-relaying and relaying areas separately. One sector of the target cell, with its relaying and non-relaying areas, is shown in Figure 3. The relaying area is the shaded area, while the rest of the sector is the non-relaying area.

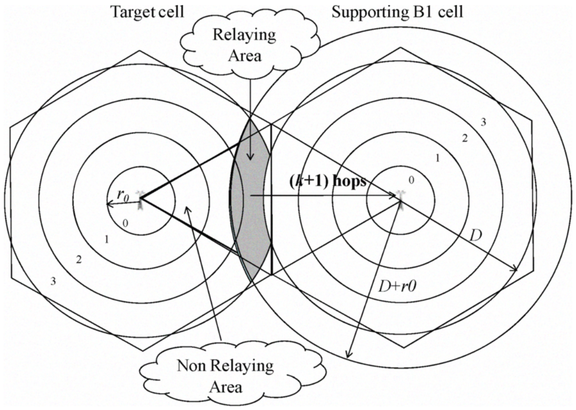

Figure 3. Relaying and non-relaying area in target cell

3.2. Interference at Target BS

Interference at a BS normally consists of intra-cell interference and inter-cell interference. In previous work [9], we derived formulas for intra-cell and inter-cell interference without inter-cell relay, which respectively are

$$I_{IntraBS} = N_0 S_R + \sum_{i=1}^{k-1}\left[\frac{N_i}{A(i)}\int_0^{2\pi}\int_{r_{i-1}}^{r_i} S_i(r) r^{-m+1}\,dr\,d\theta\right] \tag{2}$$

$$I_{InterBS} = \frac{N_0 S_R}{A(0)}\int_0^{2\Pi}\int_0^{r_0}\frac{r^{m+1}}{\left(r^2+L^2-2Lr\cos(\theta)\right)^{\frac{m}{2}}}\,dr\,d\theta + \sum_{i=1}^{k-1}\left[\frac{N_i}{A(i)}\int_0^{2\Pi}\int_{r_{i-1}}^{r_i}\frac{S_i(r)r}{\left(r^2+L^2-2Lr\cos(\theta)\right)^{\frac{m}{2}}}\,dr\,d\theta\right] \tag{3}$$

where k is the number of discs in a cell, N_i is the number of transmitting MTs in disc i, S_R is the required power of received signal, L is the distance between two adjacent BSs, $A(i)$ and r_i are the area and outer radius of disc i respectively. $S_i(r)$ is the function of transmission power of MT in disc i, which is at a distance r from BS.

Relaying calls from one cell to an adjacent BS changes the resulting interference and adds a new component. Accordingly, interference at the target BS now consists of intra-cell interference, inter-cell interference and the new interference component - relaying interference. Inter-cell interference is the interference resulting from calls originating inside adjacent cells and connected to their BSs. Inter-cell interference remains the same as the case without inter-cell relay and can still be represented by equation (3). The other two terms need more involved analysis.

Intra-cell Interference

Intra-cell interference results from calls connected to the BS of the target cell. The intra-cell interference formula has to be modified to accommodate only calls inside the target cell, which are connected to the target BS. These are calls, which originate inside the non-relaying area of target cell.

We integrate over only one sector of each disc, since all sectors are identical. Each sector has one neighboring BS facing it. The condition for a call to originate inside the non-relaying area then becomes that the distance to the BS facing this sector is larger than ($D + r_0$). The intra-cell interference at a target BS, when inter-cell relay is applied, can then be expressed as

$$I_{IntraTgBS} = \sum_{i=0}^{k-1}\left[N_{NR\_i} * I_{Intra\_NRA\_hopi}\right] \tag{4}$$

$$I_{Intra\_NRA\_hopi} = \begin{cases} S_R & i = 0 \\ \dfrac{1}{NRSA(i)}\displaystyle\int_{-\pi/6}^{\pi/6}\int_{r_{i-1}}^{r_i} S_i(r) r^{-m+1}\,dr\,d\theta & 1 \le i \le k \\ given \quad \sqrt{r^2+L^2-2Lr\cos(\theta)} > D + r0 & \end{cases}$$

where N_{NR_i} and $I_{Intra\_NRA\_hopi}$ are the number of calls and the intra-cell interference caused by a single-hop inside the non-relaying area of disc i, respectively. $NRSA(i)$ is the non-relaying area per sector of disc i.

Relaying Interference

Relaying interference results from calls inside the target cell relayed to adjacent BSs. Each adjacent B1 BS can support calls that lie inside its relaying area (shaded area in Figure 3). Each relayed call has (k + 1) hops. For this reason, the relaying interference from one supporting B1 BS at the target BS is

$$I_{relayingTg\ BS\_1} = N_R\sum_{i=0}^{k} I_{relaying\_hopi} \tag{5}$$

$$I_{relaying\_hopi} = \begin{cases} \dfrac{S_R}{SA(0)}\displaystyle\int_{-\pi/6}^{\pi/6}\int_0^{r_0}\frac{r^{m+1}}{\left(r^2+L^2-2Lr\cos(\theta)\right)^{m/2}}\,dr\,d\theta & i = 0 \\ \dfrac{1}{SA(i)}\displaystyle\int_{-\pi/6}^{\pi/6}\int_{r_{i-1}}^{r_i}\frac{S_i(r)r}{\left(r^2+L^2-2Lr\cos(\theta)\right)^{m/2}}\,dr\,d\theta & 0 < i < k \\ \dfrac{1}{RA}\displaystyle\int_{-\pi/6}^{\pi/6}\int_D^{D+r_0}\frac{S_i(r)r}{\left(r^2+L^2-2Lr\cos(\theta)\right)^{m/2}}\,dr\,d\theta & i = k \\ given \quad \sqrt{r^2+L^2-2Lr\cos(\theta)} < D & \end{cases}$$

where N_R is the number of calls relayed to one neighboring BS, and $I_{relaying\_hopi}$ is the interference resulting from one hop of the relayed call inside disc i in the B1 cell. $SA(i)$ is the sector area of disc i and RA is the relaying area per adjacent BS. It can be noticed that the summation in (5) goes from 0 to k and not only (k – 1). This is because relaying to adjacent BSs needs an extra hop than the maximum allowed by the number of discs. It has to be noted that integration for relaying interference is done over the area of one sector per disc only, which is the closest sector to the target cell. Here, the integration over the whole disc differs from integrating over only one sector. Sectors inside adjacent cells have different interference effect on the target BS, which is why relaying interference has to be calculated separately. Relayed calls reside inside the target cell and all their hops fall inside the sector closest to the target cell. Accordingly, the average relaying interference per call is higher than the average inter-cell interference per call.

Finally, the total interference at the target BS, when calls are inter-cell relayed to adjacent BSs, is the sum of all three interference components and can be expressed as

$$I_{TgBS} = \sum_{i=0}^{k-1}\left[N_{NR\_i} * I_{Intra\_NRA\_hopi}\right] + I_{InterTgBS\_call}\sum_{c=0}^{5} N_{B1\_c} + \sum_{c=0}^{5} N_{R\_c}\sum_{i=0}^{k} I_{relaying\_hopi} \tag{6}$$

where $I_{InterTgBS\_call}$ is the average inter-cell interference per call. Summation is used in the second and third terms to allow for B1 cells to have different loads and to support different number of relayed calls.

3.3. Interference at Supporting BSs

Interference at all supporting BSs is identical. Without loss of generality, interference here is calculated at the BS of the B1 cell numbered 0. At each supporting BS, interference also consists of three components which are intra-cell interference, inter-cell interference and relayed interference. Intra-cell interference is the interference resulting from calls originating inside the cell of the supporting BS, where interference is calculated, and are connected to its BS. Intra-cell interference is the same as intra-cell interference without inter-cell relay which is expressed by equation (2).

Inter-cell Interference

Inter-cell interference results from calls connected to the six cells surrounding the cell of the supporting BS, where interference is calculated. These six cells are target cell, two B1 cells and three B2 cells as shown in Figure 2. Inter-cell interference coming from B2 cell is the same as inter-cell interference defined by equation (3).

Inter-cell Interference from B1 Cell

The inter-cell interference coming from one supporting B1 cell consists of two components. The first component is the interference from calls originally inside the cell of the supporting BS and connected to the supporting BS itself. This component is the same as inter-cell interference defined by equation (3).

The second component is the interference from calls originating inside the target cell and relayed to the B1 BS. The inter-cell interference coming from one supporting B1 cell is then given by

$$I_{InterSBS\_B1} = I_{InterBS\_1} + N_R \sum_{i=0}^{k} I_{InterSBS\_relayed\_hopi} \tag{7}$$

$$I_{InterSBS\_relayed\_hopi} = \begin{cases} \dfrac{S_R}{SA(0)} \displaystyle\int_{\pi/6}^{\pi/2}\int_{0}^{r_0} \frac{r^{m+1}}{\left(r^2 + L^2 - 2Lr\cos(\theta)\right)^{m/2}} drd\theta & i = 0 \\ \dfrac{1}{SA(i)} \displaystyle\int_{\pi/6}^{\pi/2}\int_{r_{i-1}}^{r_i} \frac{S_i(r)r}{\left(r^2 + L^2 - 2Lr\cos(\theta)\right)^{m/2}} drd\theta & 0 < i < k \\ \dfrac{1}{RA} \displaystyle\int_{\pi/6}^{\pi/2}\int_{D}^{D+r_0} \frac{S_i(r)r}{\left(r^2 + L^2 - 2Lr\cos(\theta)\right)^{m/2}} drd\theta \quad given \quad \sqrt{r^2 + L^2 - 2Lr\cos(\theta)} < D & i = k \end{cases}$$

where $I_{InterBS\_1}$ is the inter-cell interference resulting from one neighboring cell as defined by equation (3). $I_{InterSBS\_relayed\_hopi}$ is the inter-cell interference resulting from one hop of each call relayed from the target cell to B1 BS. The last expression represents the extra hop needed by the MT inside the target cell to reach a MT inside the area of the supporting BS. The integration limits guarantee that MTs reside inside the relaying area of B1 BS. The condition once more guarantees that MTs are actually inside the area of the target cell. Relayed calls always need (k + 1) hops to reach supporting BS, hence the summation goes from 0 to k. It has to be noted that these calls and all their hops lie inside one sector, which is the one closest to the target cell.

Inter-cell Interference from Target Cell

The interference from the target cell is the same as inter-cell interference without applying inter-cell relay, but integrations are done on the non-relaying area only. Again, we integrate over each disc while applying the condition that guarantees calls originate inside the non-relaying area of the target cell. Each disc is divided into six sectors to make the condition in the integrations easier. The different sectors do not have the same interference effect at the supporting BS since they are not equidistant from it. Interference from each sector has to be calculated separately. Inter-cell interference from the target BS can then be calculated as

$$I_{InterSBS\_Tg} = \sum_{i=0}^{k-1} N_{NR\_i} I_{InterSBS\_Tg\_hopi} \tag{8}$$

$$I_{InterSBS\_Tg\_hopi} = \begin{cases} \dfrac{1}{NRSA(0)} \displaystyle\sum_{s=0}^{5} \left[\int_{(2s-1)\pi/6}^{(2s+1)\pi/6} \int_{0}^{r0} \frac{r^{m+1}}{r^2 + L^2 - 2Lr\cos\theta} drd\theta \quad given \quad \sqrt{r^2 + L^2 - 2Lr\cos(\theta - (2s\pi/6))} > D + r_0 \right] & i = 0 \\ \dfrac{1}{NRSA(i)} \displaystyle\sum_{s=0}^{5} \left[\int_{(2s-1)\pi/6}^{(2s+1)\pi/6} \int_{r_{i-1}}^{r_i} \frac{S_i(r)r}{r^2 + L^2 - 2Lr\cos\theta} drd\theta \quad given \quad \sqrt{r^2 + L^2 - 2Lr\cos(\theta - (2s\pi/6))} > D + r_0 \right] & 1 \le i \le k \end{cases}$$

where $I_{InterSBS\_Tg\_hopi}$ is the inter-cell interference per hop coming from the non-relaying area of disc i of the target cell. $NRSA(i)$ is the non-relaying area per sector of disc i. Equation (8) sums interference over all calls connected to the target BS and all their hops. The conditions in integrations guarantee that calls lie inside the non-relaying area of the target cell.

Relayed Interference

The last component of interference at the supporting BS is relayed interference, which results from calls originating inside the target cell and relayed to the supporting BS, where interference is calculated. All these calls reside inside the relaying area of B1 BS numbered 0. Summing the interference coming from all the (k + 1) hops, the relayed interference at the supporting BS can be represented as

$$I_{relayedSBS} = N_{R\_0} \sum_{i=0}^{k} I_{relayedSBS\_hopi} \tag{9}$$

$$I_{relayedSBS\_hopi} = \begin{cases} S_R & i = 0 \\ \dfrac{1}{SA(i)} \displaystyle\int_{-\pi/6}^{\pi/6} \int_{r_{i-1}}^{r_i} S_i(r) r^{-m+1} drd\theta & 1 \le i \le k-1 \\ \dfrac{1}{RA} \displaystyle\int_{-\pi/6}^{\pi/6} \int_{D}^{D+r_0} S_i(r) r^{-m+1} drd\theta \quad given \quad \sqrt{r^2 + L^2 - 2Lr\cos(\theta)} < D & i = k \end{cases}$$

where N_{R_0} is the number of calls relayed to the supporting BS in consideration, $I_{relayedSBS\_hopi}$ is the interference resulting per hop i per relayed call. Again, the condition in the last integration guarantees that all relayed calls lie inside the target cell. The integrations are done on one sector since all relayed calls and their hops lie in one sector which is the closest to the target BS. Equation (9) sums over all hops of the relayed calls, hence the summation from 0 to k. The last expression calculates the interference coming from the extra hop needed by the MT inside the target cell to reach a MT inside the cell of the supporting BS. Again, the limits of the integration along with the condition define the relaying area shown in Figure 3.

The total interference at a supporting BS is the sum of all three interference components. It has to be noted that each supporting B1 BS is surrounded by the target cell, two supporting B1 cells and three B2 cells as shown in Figure 2. Adding all interference components, the total interference at a supporting BS can be expressed as

$$I_{SBS} = N_{B1\_0} I_{IntraSBS\_call} + \sum_{c \in \{1,5\}} N_{R\_c} \sum_{i=0}^{k} I_{InterSBS\_relayed\_hopi} + \sum_{i=0}^{k-1} N_{NR\_i} I_{InterSBS\_Tg\_hopi}$$
$$+ N_{R\_0} \sum_{i=0}^{k} I_{relayedSBS\_hopi} + I_{InterBS\_call} \left(\sum_{c \in \{11,0,1\}} N_{B2\_c} + \sum_{c \in \{1,5\}} N_{B1\_c} \right) \quad (10)$$

where $I_{IntraSBS\_call}$ and $I_{InterSBS\_call}$ are respectively the intra-cell and inter-cell interference per call. The index c in the variables allows different B1 and B2 cells to have different number of calls for more generalized form. The suffix 0 indicates the supporting BS in consideration, where interference is calculated. It can be noticed that in the summation over B1 and B2 cells, the set form is used. This is due to the fact that the B1 cells, which are adjacent to B1 cell numbered 0, are B1 cells 1 and 5. The adjacent B2 cells are the 0, 1 and 11. Figure 2 further illustrates this arrangement.

4. Results and Discussion

In previous section, we derived formulas to quantify interference. In this section, the number of supported calls inside the area of the target cell is calculated. The number of calls accepted at any BS depends on the interference experienced at the BS. The pre-determined quality of calls based on the application nature has to be maintained. In this paper, the quality of calls is taken to be a certain data rate at a maximum Bit Error Rate (BER). BER can be maintained below a certain bound by keeping the bit energy to interference ratio (E_b/I_0) above certain threshold (τ). E_b/I_0 is calculated from the Signal to Interference Ratio (SIR) by dividing the power of the desired signal by the allocated data rate (R) and the interference power by the bandwidth (W). The above discussion leads to the following condition

$$\tau \leq \frac{W \; S_R / R}{I_{Tot} - S_R} \quad (11)$$

where S_R is the required power of the desired signal and I_{Tot} is the total received power of interference. Substituting total interference formulas previously derived (equations (2) and (3)) in (11) and re-arranging, an upper bound on number of calls, when no inter-cell relay is applied, can be formed as

$$N_{Tg} \leq \frac{W/\tau R + 1 - I_{InterBS\_call} \sum_{c=0}^{5} N_{B1\_c}}{I_{IntraBS\_call}} \quad (12)$$

where $I_{IntraBS\_call}$ is the intra-cell interference per call. The maximum number of calls that can be supported inside the area of the target cell without inter-cell relay is tabulated in Table 1 versus the number of calls inside adjacent B1 cells. In all results, we assume that all cells other than target cell have the same load (i.e. $N_{B1\_c} = N_{B2\_c} = N_B$ *for* all values of c). The values of the parameters used in the calculations are shown in Table 2.

Table 1. Number of calls in Target cell and total number of calls in 19-cell cluster

	Heavy Loaded B1 cells ($N_B = N_{Tg}$)		Half loaded B1 cells ($N_B = 10$)		Lightly loaded B1 cells ($N_B = 5$)	
Number of discs	Total calls in cluster	N_{Tg}	Total calls in cluster	N_{Tg}	Total calls in cluster	N_{Tg}
1	361	19	202	22	114	24
2	437	23	204	24	114	24
3	437	23	203	23	113	23
4	437	23	203	23	113	23
5	437	23	203	23	113	23
6	437	23	203	23	113	23

Table 2. Parameters used in results

Path Loss	m	4
Frequency Band	W	1.22 MHz
Data Rate	R	9.6 Kbps
Max. Bit Error Rate	BER	10^{-3}
E_b/I_0 Threshold	τ	5 (7 dB)

It can be noticed that variation in the load of adjacent cells has minor effect on the capacity of the target cell. Although the total number of calls has dropped to half its maximum, the maximum number of calls that can be supported inside the area of the target cell has hardly changed and congestion still occurs. The problem is that calls originating inside target cell area cannot use the available resources in adjacent cells. This motivates the application of inter-cell relay.

Using inter-cell relay, some calls originally inside the area of the target cell can be relayed to BSs of less loaded B1 cells. Substituting total interference at the target BS defined by equation (6) into (11) and re-arranging, the upper bound on the density of calls inside the area of target cell, when applying inter-cell relay can be expressed as

$$\rho_{Tg} \leq \frac{W/\tau R + 1 - 6 * N_B * I_{InterTgBS\_call}}{6 \sum_{i=0}^{k-1} \left[NRSA(i) * I_{Intra\_NRA\_hopi} \right] + 6 * RA * \sum_{i=0}^{k} I_{relaying\_hopi}} \quad (13)$$

The upper bounds on number of calls that can be supported inside the congested cell with and without inter-cell relay are plotted in Figure 4.

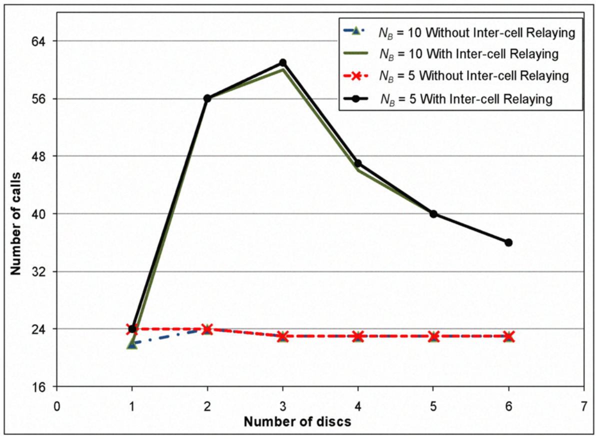

Figure 4. Upper bound on number of calls inside target cell with and without inter-cell relay

Figure 4 shows that the number of calls that can be supported inside the area of the target cell increases by inter-cell relay. The number is doubled in some scenarios. This emphasizes the benefits gained from using inter-cell relay, which takes advantage of available resources in less loaded cells to relieve congestion of other cells. It can be noted that the number of supported calls first increases with the increase in number of discs then decreases. This can be explained by the scheme chosen to determine which MTs relay their calls to adjacent BSs. Based on the scheme, the relaying area decreases when increasing the number of discs, which results in fewer calls relayed.

To guarantee the quality of relayed calls, the level of interference at the supporting BS has to be controlled. Using (10), the interference at the supporting BS is calculated. Results from these calculations, which are not shown due to space limitation, show that the quality of calls connected to supporting BSs is maintained. The results further illustrates that supporting BSs can support more calls. To allow more calls to be relayed, the number of calls connected to the target BS has to be decreased to lower interference level at the target BS. This can be achieved by increasing the relaying area, hence decreasing the non-relaying area of the target cell. An algorithm to decide the size of the relaying and non-relaying areas has to be devised to maximize the number of calls supported inside area of a congested cell. Due to space limitation, changing the relaying and non-relaying areas to maximize number of supported calls will be presented in future work.

5. Conclusion

Multihop communication is proposed to overcome some drawbacks of cellular networks. One of the promised advantages is congestion relief. In traditional single-hop cellular networks, MTs inside congested cell cannot make use of available resources in adjacent less loaded cells. In MCNs, inter-cell relay can be applied to divert calls originating in one cell to adjacent less loaded cells for congestion relief or load balancing.

In this paper, we analyze inter-cell relay in CDMA-based MCNs. Inter-cell relay changes the resulting interference. We derive formulas to calculate interference when inter-cell relay is applied. Interference is calculated at the congested BS as well as at the supporting BSs. Results based on derived formulas show that the number of calls can be increased inside a congested cell using inter-cell relay. We show that the number of calls can be doubled in some scenarios. Due to space limitation, detailed gains in congestion relief and load balancing along with a scheme to determine the size of relaying area to maximize the number of accepted calls will be presented in future publications.

6. Reference

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