Coverage and Capacity Enhancement of CDMA Cellular Systems via Multihop Transmission

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***Abstract*— The uplink coverage and capacity of CDMA cellular systems are intracell and intercell interference limited. In this work, we propose a practical multihop based cellular network design to enhance the uplink performance. The proposed design is based on dividing each cell into two regions where users belonging to an inner region communicate with the base station (BS) using one hop and users belonging to an outer region communicate with the BS using two hops. Each of the two regions is allocated a separate frequency channel to enable practical implementation and reduce interference. Analytic results show that intercell interference in CDMA cellular systems can be reduced by more than 75%. Moreover, a link budget analysis is performed to obtain coverage–capacity results with different receiver structures at the BS. Results show that with the single user detector (SUD) receiver, gains up to 100% in area coverage are achieved with moderate to low user loads. Furthermore, deploying multiuser detection to combat intracell interference, the proposed multihop based design achieves very high gains exceeding 100% in pole capacity and 300% in area coverage per cell.**

I. Introduction

A major design issue for wireless cellular networks is the number of cells required to cover a given area of interest with given user load requirements. The coverage of a cell is defined as the area covered by one base station (BS) and the capacity of a cell is defined as the number of mobile stations (MSs) that the BS can reliably support. CDMA has been selected as the accessing scheme for the CDMA2000 and UMTS systems due to its service flexibility and improved performance. In CDMA, all users in all cells are active at the same time using the same frequency channel and spreading is used to differentiate the signals of different users. An orthogonality between the spreading sequences cannot be maintained at the receiver in the uplink due to asynchronous transmission and multipath propagation. Therefore, the cell coverage and capacity are uplink limited in many practical scenarios due to intracell interference from users active in the same cell and intercell interference from users active in neighboring cells.

A direct way to increase system coverage or capacity is to create more cells. However, the network infrastructure costs increase significantly as the number of cells increases. Therefore, there is a need to find other enhancement techniques with lower costs and practical complexity. Many techniques have been proposed to enhance the uplink coverage and capacity by combating the intracell interference, increasing the diversity order, or increasing the antenna gain at the BS, e.g. multiuser detection, beamforming, or sectorization [1], [2]. A major limiting factor to the enhancements achieved by all these techniques is the presence of intercell interference which in typical cellular scenarios ranges between 50% and 100% of the value of the intracell interference at the BS [3].

In this work, we propose a multihop based cellular network design to enhance the uplink performance of CDMA cellular systems by mainly combating the intercell interference. The main idea behind the proposed design is to let part of the users in each cell, depending on their location, communicate with the BS using two hops. The interference at all receiving nodes in the network is analytically calculated and a link budget analysis to evaluate coverage and capacity gains over the conventional design is performed as a function of various parameters including the receiver structure used at the BS.

The idea of using multihop transmission to enhance cellular networks goes back to the use of repeaters that perform analog retransmission and that are applied mainly in hot spots or hard–to–reach areas. Recently, a lot of work is being done on the possible enhancement of cellular systems via multihop transmission with more intelligent relaying [4], [5], [6]. Most of the presented results are based on simulations for specific scenarios, complex to realize in a practical system, and evaluated mainly in terms of throughput or user capacity gain.

Section II describes the proposed multihop based network design. In Section III, the resulting system model is presented and the interference is analytically calculated. Then, capacity–coverage results obtained via a link budget analysis are discussed in Section IV and conclusions are drawn in Section V.

II. Multihop based Cellular Networks

The adopted system model is the uplink of a CDMA cellular system with hexagonal cells of radius R_{cell} and K mobile stations (MSs) per cell. Each cell is equipped with an omni–directional antenna at its BS. Moreover, all MSs belong to the same service class with spreading factor SF.

The main idea behind the proposed design is to use multihop transmission in *all* cells in the network where each cell is divided into two regions as depicted in Fig. 1. Each MS inside a circular region of radius τR_{cell}, $\tau \leq 1$, around the BS communicates using one hop and each MS outside the circular region communicates using two hops via one relay station (RS). The RSs are assumed to be located on the perimeter of the circle and can be either normal MSs or fixed stations placed by the network operator where retransmission

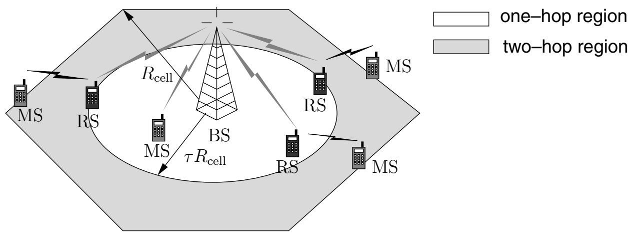

Fig. 1. A multihop based cellular network.

takes place through complete signal detection. Using normal MSs as RSs is motivated by the existence of a large number of idle MSs that are switched on in any given area. This leads to simple routing which depends mainly on the design parameter τ that can be selected to achieve the best gain. Two central design issues to the implementation of the proposed design in practice are the accessing scheme and relay selection strategy.

A. Accessing Scheme

Using multihop transmission in cellular networks introduces a new set of communication links between the two–hop MSs and their RSs that must be allocated the required resources. This is one of the limiting problems in designing practical multihop based cellular networks especially because a RS cannot receive and transmit at the same time using the same frequency channel. However, taking advantage of the proposed RS locations and the limited allowed number of hops, we present a solution to the accessing problem depending on whether the CDMA system is time division duplex (TDD) or frequency division duplex (FDD) based as depicted in Fig. 2.

For TDD based systems, two frequency channels that are distant enough are needed where the one–hop MSs and the active RSs communicate with the BS using one channel (f_1) and the two–hop MSs communicate with their RSs using the other channel (f_2). Therefore, any normal MS can act as a RS and each RS can communicate simultaneously with its relayed MS and its BS without the need for a new air interface.

For FDD based systems, fixed relay stations (fRSs) located at specific positions and two paired frequency channels for the MS–fRS and the MS/fRS–BS links should be used. The fRSs are assumed to be uniformly distributed on the boundary of the circular region around the BS where each fRS can avoid signal masking and frequency swapping problems by using two spatially separated antennas. A fRS is more complex than a normal MS due to the use of two antennas and can relay an arbitrary number of MSs. Note that most network operators have usually licenses for more than one frequency channel which allows the implementation of the proposed schemes.

B. Relay Selection Strategy

The relay selection strategy determines which RS to allocate to a given two–hop MS. In TDD systems, the closest RS which is located on the circle boundary is selected. This method of relay selection in combination with power control provides a situation where signals from other two–hop MSs are received at a given RS with at most the same power as the signal from its served MS which reduces the possibility of signal masking problems due to arbitrary positions of RSs and MSs. In FDD systems, the fRS selection procedure is the same, i.e. the closest fRS is selected. In both cases, the BS takes care of the selection of the (f)RS to serve a given MS. Each MS, one–hop or two–hop, is assumed to be able to communicate signaling and control information with its BS.

III. System Analysis and Interference Estimation

Due to the orthogonal accessing, the system analysis can be performed independently for each region in the cell. The receiver structure used at the BS is either the conventional single user detector (SUD) or an advanced multiuser detector such as multistage interference canceler (IC) that treats all users symmetrically and combats intracell interference. However, the receiver used at the RSs is SUD due to its low complexity.

The total number of MSs per cell, K, is divided into $K_{\rm d}$ one–hop MSs and $K_{\rm r}$ two–hop MSs. The BS communicates with $K_{\rm d}$ one–hop MSs and $K_{\rm r}$ RSs that relay the two–hop MSs. The average uplink SIR of MS/RS k, $k \in [1, K]$, at its BS can be written as

$$\mathrm{SIR}_{\mathrm{BS}_k} = \frac{P_{\mathrm{BS}_k}}{\frac{1}{\mathrm{SF}}\left(\sigma^2_{\mathrm{BS}} + \alpha_{\mathrm{BS}}\sum_{l=1}^{K} P_{\mathrm{BS}_l} + \lambda \sum_{l=1, l\neq k}^{K} P_{\mathrm{BS}_l}\right)}, \quad (1)$$

where P_{BS_k} is the received power of MS/RS k at its BS, σ^2_{BS} is the thermal noise variance at each BS, α_{BS} is the ratio of the intercell interference power and the total intracell received power at the BS, and λ is a residual interference cancellation factor that models the receiver structure [7]. For SUD $\lambda = 1$ while for IC $\lambda \in [0, 1]$. Using power control, all MSs/RSs in each cell must be received with the same power at the BS to achieve their target SIR due to the symmetric detection conditions in the receiver, thus, $P_{\mathrm{BS}_k} = P_{\mathrm{BS}}$.

On the other hand, the average SIR at the RS of the two–hop MS k, RS_k, $k \in [1, K_{\rm r}]$, can be written as

$$\mathrm{SIR}_{\mathrm{RS}_k} = \frac{P_{\mathrm{RS}_{kk}}}{\frac{1}{\mathrm{SF}}\left(\sigma^2_{\mathrm{RS}} + \alpha_{\mathrm{RS}_k}\sum_{l=1}^{K_{\rm r}} P_{\mathrm{RS}_{ll}} + I_{\mathrm{intra}_k}\right)}, \quad (2)$$

where $P_{\mathrm{RS}_{lk}}$ is the received power of MS l at the RS of MS k, σ^2_{RS} is the thermal noise variance at each RS, α_{RS} is the ratio of the total power coming from other cells (intercell interference) and the sum of the signal powers of own cell two–hop MSs at their respective RSs, and I_{intra_k} is the interference at the RS of MS k coming from the same cell (intracell interference) which is given by

$$I_{\mathrm{intra}_k} = \sum_{l=1, l\neq k}^{K_{\rm r}} P_{\mathrm{RS}_{lk}} = \alpha_{\mathrm{RS}0}\sum_{l=1}^{K_{\rm r}} P_{\mathrm{RS}_{ll}} - P_{\mathrm{RS}_{kk}}, \quad (3)$$

where $\alpha_{\mathrm{RS}0}$ is defined as the ratio of the total power coming from own cell two–hop MSs at a given RS and the sum of the signal powers of own cell two–hop MSs at their respective RSs. Assuming that all RSs face the same average total interference, the received power of all two–hop MSs at their

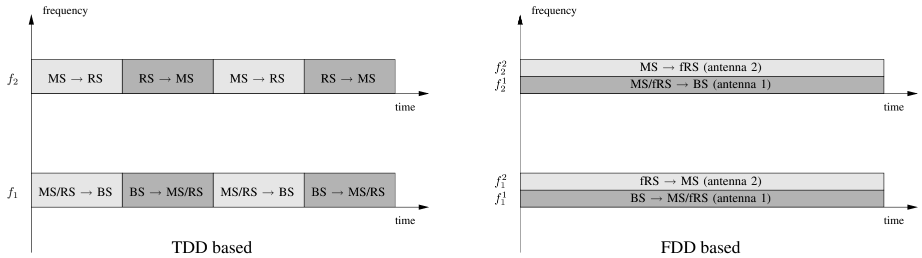

Fig. 2. Accessing schemes for the multihop based cellular network design.

respective RSs should be the same to achieve their target SIR with minimum transmit power, thus, $P_{\mathrm{RS}_{kk}} = P_{\mathrm{RS}}$.

The transmit power of each MS/RS can be calculated by multiplying its required received power by the path loss $\kappa \cdot r^{\mu}$ where μ is the path loss exponent, r is the distance between the transmitting and receiving stations, and κ is an equivalent path loss constant which depends on various parameters including the antenna heights and gains, carrier frequency, transmitter and receiver losses, etc.

A. Interference Estimation

Before a link budget analysis can be performed, the defined interference ratios are calculated in this section. To simplify the calculations, each hexagonal cell of radius R_{cell} is modeled as a circular cell of radius R having the same area. Moreover, the radius of the circular region around the BS is assumed equal to τR as shown in Fig. 3. The users in each cell are uniformly distributed with density per unit area ρ given by

$$\rho = \frac{K}{(3\sqrt{3}/2)R_{\mathrm{cell}}^2} = \frac{K}{\pi R^2}. \tag{4}$$

Therefore, the number of one–hop and two–hop MSs can be calculated as $K_{\mathrm{d}} = \tau^2 K$ and $K_{\mathrm{r}} = (1-\tau^2)K$, respectively.

Due to the symmetric conditions in the network, the interference will be calculated at the reference stations RS_0 and BS_0. We assume that each two–hop MS is connected to the BS over the shortest path, i.e. the RS is on the line joining the MS to the BS, which minimizes the transmit power and, thus, the interference. The obtained values apply to the TDD based model and serve as a lower bound for the FDD model.

The reference BS, BS_0, is surrounded by T tiers of cells where each tier t has $6t$ cells. The position of cell i in tier t,

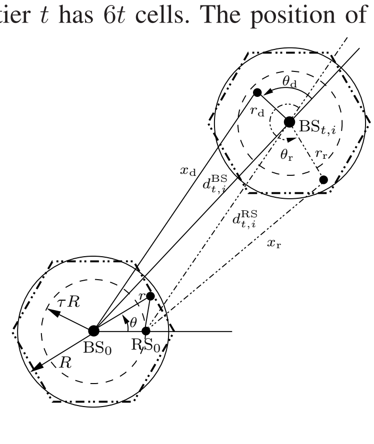

Fig. 3. Two hexagonal cells modeled as circles.

where $i \in [0, 6t-1]$, can be expressed in vector form as

$$\vec{R}_{t,i} = \left(\sqrt{3}tR_{\mathrm{cell}} + \sqrt{3}\,(i \bmod t)\,R_{\mathrm{cell}}e^{j\frac{2\pi}{3}}\right)e^{j\lfloor\frac{i}{t}\rfloor\frac{\pi}{3}}e^{j\frac{\pi}{6}}. \tag{5}$$

The distance from $\mathrm{BS}_{t,i}$ to BS_0 and RS_0 can be calculated as $d_{t,i}^{\mathrm{BS}} = |\vec{R}_{t,i}|$ and $d_{t,i}^{\mathrm{RS}} = |\vec{R}_{t,i} - \tau R|$, respectively.

From Fig. 3, the distance between BS_0 and the user with coordinates $(r_{\mathrm{d}}, \theta_{\mathrm{d}})$ in cell $\mathrm{BS}_{t,i}$ can be expressed as

$$x_{\mathrm{d}}(r_{\mathrm{d}}, \theta_{\mathrm{d}}) = \sqrt{(d_{t,i}^{\mathrm{BS}})^2 + r_{\mathrm{d}}^2 + 2d_{t,i}^{\mathrm{BS}} r_{\mathrm{d}} \cos\theta_{\mathrm{d}}}. \tag{6}$$

Azimuth θ_{d} uses the line going through BS_0 and $\mathrm{BS}_{t,i}$ as reference. The total interference at BS_0 coming from $\mathrm{BS}_{t,i}$ is

$$\begin{aligned} P^{t,i} &= \int_0^{\tau R}\int_{-\pi}^{\pi} \rho P_{\mathrm{BS}} \left|\frac{r_{\mathrm{d}}}{x_{\mathrm{d}}(r_{\mathrm{d}}, \theta_{\mathrm{d}})}\right|^{\mu} r_{\mathrm{d}}\, dr_{\mathrm{d}}\, d\theta_{\mathrm{d}} \\ &+ \int_{-\pi}^{\pi} \frac{K_{\mathrm{r}}}{2\pi} P_{\mathrm{BS}} \left|\frac{\tau R}{x_{\mathrm{d}}(\tau R, \theta_{\mathrm{d}})}\right|^{\mu} d\theta_{\mathrm{d}}. \end{aligned} \tag{7}$$

Taking into account the network symmetry, the intercell to intracell interference ratio α_{BS} can be calculated as

$$\alpha_{\mathrm{BS}} = \frac{6\sum_{t=1}^{T}\sum_{i=0}^{t-1} P^{t,i}}{K P_{\mathrm{BS}}}. \tag{8}$$

The distance between a two–hop MS belonging to BS_0 with coordinates (r, θ) and RS_0 can be expressed as

$$x(r, \theta) = \sqrt{r^2 + (\tau R)^2 - 2r(\tau R)\cos\theta}. \tag{9}$$

Therefore, the total received power of two–hop MSs in BS_0 at RS_0 is given by

$$P^0 = \int_{\tau R}^{R}\int_{-\pi}^{\pi} \rho P_{\mathrm{RS}} \left|\frac{r - \tau R}{x(r, \theta)}\right|^{\mu} r dr d\theta. \tag{10}$$

From this, one can calculate α_{RS0} as

$$\alpha_{\mathrm{RS0}} = \frac{P^0}{K_{\mathrm{r}} P_{\mathrm{RS}}}. \tag{11}$$

The distance between RS_0 and a two–hop MS in cell $\mathrm{BS}_{t,i}$ with coordinates $(r_{\mathrm{r}}, \theta_{\mathrm{r}})$ can be expressed as

$$x_{\mathrm{r}}(r_{\mathrm{r}}, \theta_{\mathrm{r}}) = \sqrt{(d_{t,i}^{\mathrm{RS}})^2 + r_{\mathrm{r}}^2 + 2d_{t,i}^{\mathrm{RS}} r_{\mathrm{r}} \cos\theta_{\mathrm{r}}}. \tag{12}$$

Azimuth θ_{r} uses the line going through RS_0 and $\mathrm{BS}_{t,i}$ as reference. The total interference at RS_0 coming from all two–hop MSs in $\mathrm{BS}_{t,i}$ is given by

$$P^{t,i} = \int_{\tau R}^{R}\int_{-\pi}^{\pi} \rho P_{\mathrm{RS}} \left|\frac{r_{\mathrm{r}} - \tau R}{x_{\mathrm{r}}(r_{\mathrm{r}}, \theta_{\mathrm{r}})}\right|^{\mu} r_{\mathrm{r}}\, dr_{\mathrm{r}}\, d\theta_{\mathrm{r}}. \tag{13}$$

Finally, α_{RS} can be calculated as

$$\alpha_{\mathrm{RS}} = \frac{\sum_{t=1}^{T}\sum_{i=0}^{6t-1} P^{t,i}}{K_{\mathrm{r}} P_{\mathrm{RS}}}. \quad (14)$$

The calculated expressions are evaluated via numerical integration. Fig. 4 presents the values of α_{BS} as a function of μ for different values of τ and Table I presents the different α values as a function of τ for $\mu = 3.5$. Results show that as μ increases, all the interference ratios decrease due to higher path loss. For $\tau = 1$, the system corresponds to the conventional network design where $\alpha_{\mathrm{BS}} = 0.55$ at $\mu = 3.5$ which means that the intercell interference is 55% of the total intracell received signal at the BS. In this case $\alpha_{\mathrm{RS}} = \alpha_{\mathrm{RS0}} = 0$ since no RSs are used. As τ decreases, α_{BS} decreases but at the same time α_{RS} and α_{RS0} increase since more RSs are used. For $\tau = 0$, the solution is again that of the conventional design since all RSs converge to the position of the BS. In this case, α_{BS} = 0, α_{RS} is equal to α_{BS} with $\tau = 1$, and $\alpha_{\mathrm{RS0}} = 1$.

The importance of the proposed multihop based design is demonstrated by considering the case with $\tau = 0.5$ and $\mu = 3.5$. Results show that the intercell interference ratio at the BS is reduced from 0.55 to 0.07, i.e. 87% reduction. At the same time, the intracell and intercell interference ratios at the RSs are around 0.12 and 0.07, respectively, which are also around 87% less than the intracell and intercell interference ratios at the BS in the conventional network design. Therefore, it is expected that the performance will be mainly limited by the intracell interference at the BS. The obtained theoretical results are all verified via simulations which validates our assumptions, such as circular cells and symmetric interference at all RSs irrespective of their locations.

TABLE I

α VALUES AS A FUNCTION OF τ WITH $\mu = 3.5$

	$\tau = 1$	$\tau = 0.75$	$\tau = 0.5$	$\tau = 0.25$	$\tau = 0$
α_{BS}	0.55	0.29	0.07	0.007	0
α_{RS0}	0	0.05	0.12	0.3	1
α_{RS}	0	0.02	0.07	0.2	0.55

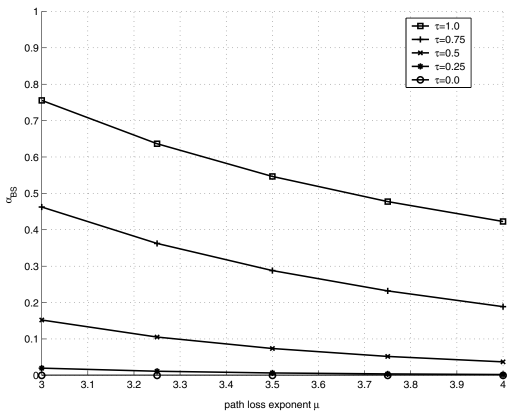

Fig. 4. Calculated values of α_{BS} as a function of μ.

IV. COVERAGE–CAPACITY ANALYSIS AND RESULTS

In CDMA cellular systems, a link budget analysis is usually performed to determine how many cells are needed to cover a given area [1], [2]. The link budget analysis is based mainly on the required received power of each MS/RS to achieve its target SIR, the maximum allowed transmit powers, and the path loss model. For a given scenario, the required received powers P_{BS} and P_{RS} can be calculated from (1) and (2) by setting a target SIR at each BS and RS. Given the required parameters, the maximum range for the MS/RS–BS links and the MS–RS links can be calculated as

$$R_{\mathrm{BS}_{\max}} = \sqrt[\mu_{\mathrm{d}}]{\frac{\min\{P_{\mathrm{T_{RS}}}, P_{\mathrm{T_{MS}}}\}}{\kappa_{\mathrm{d}} \cdot P_{\mathrm{BS}}}}, \quad (15)$$

$$R_{\mathrm{RS}_{\max}} = \sqrt[\mu_{\mathrm{r}}]{\frac{P_{\mathrm{T_{MS}}}}{\kappa_{\mathrm{r}} \cdot P_{\mathrm{RS}}}}, \quad (16)$$

respectively, where κ_{d} and μ_{d} are the path loss constant and exponent for the MS/RS–BS links, κ_{r} and μ_{r} are the path loss constant and exponent for the MS–RS links, and $P_{\mathrm{T_{RS}}}$ and $P_{\mathrm{T_{MS}}}$ are the maximum allowed transmission powers of each RS and MS, respectively. $R_{\mathrm{BS}_{\max}}$ and $R_{\mathrm{RS}_{\max}}$ determine the maximum range in each region in the cell and are functions of the α values which in turn depend on the value of τ. Moreover, from the definition of τ, the following constraint must be also taken into account in the selection of the value of τ and the coverage–capacity calculations: $(1-\tau)R_{\mathrm{BS}_{\max}} = \tau R_{\mathrm{RS}_{\max}}$.

Equations (1) and (2) can be also used to calculate the pole capacity which is defined as the maximum number of users that can be reliably supported per cell as the coverage shrinks to zero. For the proposed network design, the pole capacity can be calculated as $K_{\mathrm{pole}} = \min\{K_{\mathrm{BS_{pole}}}, K_{\mathrm{RS_{pole}}}\}$ where

$$K_{\mathrm{BS_{pole}}} = \left\lfloor \frac{\mathrm{SF} + \lambda \mathrm{SIR_{BS}}}{\mathrm{SIR_{BS}}(\lambda + \alpha_{\mathrm{BS}})} \right\rfloor, \quad (17)$$

$$K_{\mathrm{RS_{pole}}} = \left\lfloor \frac{\mathrm{SF} + \mathrm{SIR_{RS}}}{\mathrm{SIR_{RS}}\left(\alpha_{\mathrm{RS0}} + \alpha_{\mathrm{RS}}\right)\left(1-\tau^2\right)} \right\rfloor. \quad (18)$$

Given the required set of system parameters, one can calculate the values of τ, $R_{\mathrm{BS}_{\max}}$ and $R_{\mathrm{RS}_{\max}}$ for each user load K that is less than K_{pole}. The cell radius is given by the sum of the two calculated ranges: $R_{\max} = R_{\mathrm{BS}_{\max}} + R_{\mathrm{RS}_{\max}}$.

Table II presents a set of typical parameters that are used to evaluate the coverage–capacity results presented in this work [1]. The target SIR is set to 3.2 dB which achieves a BER of 10^{-3} over a Rayleigh fading channel with a rate 1/3 convolutional encoder and corresponds to $E_b/N_o = 8$ dB. The path loss parameters are obtained from the COST–231 extension of the Hata model [2]. Due to the lack of a path loss model for low height terminals, the MS–RS links are assumed to have the same path loss model as the MS/RS–BS links. The carrier frequencies are 1.9 GHz and 2.02 GHz for the MS/RS–BS and MS–RS links, respectively, which are selected according to the UMTS TDD bands in Europe.

Fig. 5 presents the calculated coverage–capacity results with SUD used at the BS ($\lambda = 1$). Since the proposed multihop

TABLE II

PARAMETERS USED FOR COVERAGE–CAPACITY RESULTS

	MS/RS–BS link	MS–RS link
SF	64	64
Target SIR	3.2 dB	3.2 dB
Chip rate	3.84 Mcps	3.84 Mcps
Tx power maximum	0.125 W	0.125 W
Tx antenna gain	0 dBi	0 dBi
Tx loss	0 dB	0 dB
Rx antenna gain	10 dBi	0 dBi
Rx loss	2 dB	0 dB
Rx noise figure	5 dB	7 dB
Body loss	2 dB	4 dB
Path loss exponent μ	3.52	3.52
Path loss constant κ	137 dB	138 dB

based network design uses two frequency channels, the results are presented for the conventional design with one and two frequency channels per cell for a fair comparison. It is shown that the multihop based design outperforms the conventional design in terms of coverage providing a gain up to 43% in cell radius which corresponds to around 100% increase in area coverage per cell. This gain is achieved mainly at low to moderate user loads. Moreover, a gain in user capacity is realized only at high cell range, e.g. the number of users per cell increases from 15 to 27 at a cell radius equal to 1.5 km. On the other hand, the conventional design with two frequency channels has a better performance in terms of pole capacity (40 to 31 users per cell).

However, by deploying a multistage IC at the BS to combat the intracell interference [7], the gains achieved by the proposed design are remarkable as shown in Fig. 6 with $\lambda = 0.05$. The coverage gain at low loads remains the same as with the SUD receiver since intracell interference is not the limiting factor. On the other hand, very high enhancements are achieved as the load increases. The pole capacity is increased by 113% (104 to 225 users per cell) compared to the conventional design with IC at the BS and two frequency channels, and by 625% (31 to 225 users per cell) compared to the multihop based design with SUD at the BS. Moreover, the coverage gain at high loads is also notably high, e.g. at $K = 90$ users the area coverage per cell for the proposed design is around 300% more than the conventional design

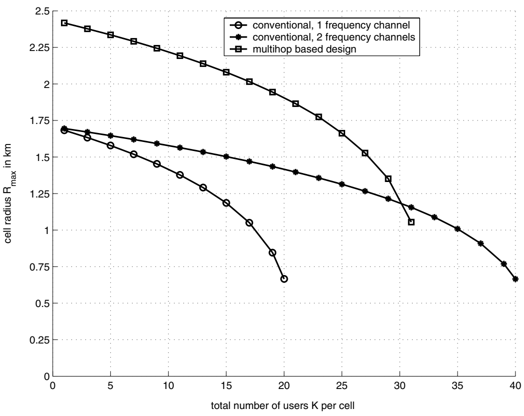

Fig. 5. Coverage–capacity results with SUD receiver ($\lambda = 1$).

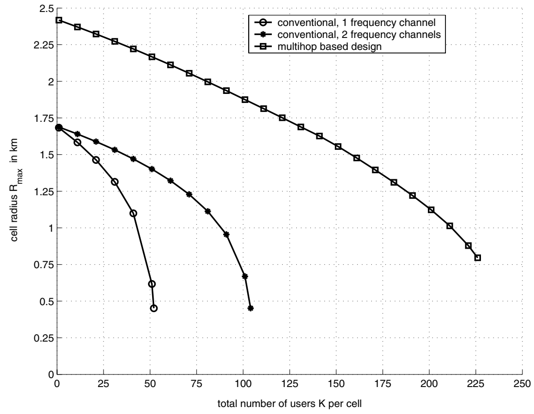

Fig. 6. Coverage–capacity results with IC receiver ($\lambda = 0.05$).

($R_{\max}$ increases from 1 km to 2 km). Note that the typical values of τ selected in the different scenarios vary between 0.5 and 0.7. The main reason behind these gains is that the intercell interference at the BS is reduced by the multihop based design and the intracell interference at the BS is reduced by the enhanced receiver structure.

The presented absolute gains are an upper limit on the possible gains in practice since many effects such as shadowing, penetration losses, and coverage margins are not considered to facilitate the analytical analysis. However, it is expected that the relative gains over the conventional design will roughly stay the same after these effects are taken into account.

V. CONCLUSIONS

We have proposed a practical multihop based network design that is capable of achieving significant coverage and capacity gains over the conventional cellular design especially when an advanced receiver structure is used at the BS.

Some other issues that should be accounted for in a practical implementation are the need for fixed RSs at low user loads (roll–out phase) since not enough MSs might be available to be used as relays, signaling protocols, handover algorithms, security guarantees, and billing criteria.

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