Cost/Performance Trade-offs of "Two-Layers" Ad Hoc Multihop Cellular Access Systems

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***Abstract*— Ad Hoc multihop cellular access is considered to be a strong candidate for the next generation of public phone systems. In this paper, we present a novel approach for solving the dimensioning problem of an ad hoc system capable of two-hops transmissions. In this respect, is presented and analyzed a method for comparing the expenditure levels, for deploying and running a cellular network, implemented through a multihopping system or through a standard cellular solution selected as reference. In particular, we describe the conditions in which the proposed multihopping solution is feasible, and quantify the performance/cost trade-offs that are achievable. Numerical results show that the spectral efficiency of currently deployed single hop systems can almost be doubled, if the user terminals are capable of multihopping and the cell planning is performed so that a critical mass of user per cell can be guaranteed.**

I. Introduction

The majority of the systems that are currently in use have been designed for providing cost effective universal coverage for limited number of users with moderate data rates demand [1]. Concurrently, the large use of Internet-based service and multimedia are driving the development of wireless applications toward the need for larger bandwidths. At the same time, it has to be faced an *implicit postulate*: the cost of these wideband services is limited by the one that has been set by current voice services. A quite clear trade-off is presented in [2], where it is shown that, providing universal wideband coverage, with the current deploying paradigms, will lead to end-user connection costs proportional to the bandwidth provided. This trade-off seems to partially explain the current roll-out difficulties faced by 3G networks: the level of expenditures for building and running these networks is much larger than for concurrents 2-2.5G systems, while the price for the end users cannot be set proportionally higher. Therefore, looking in future perspective, or some QoS requisites have to be compromised (e.g. universal coverage should be substitute by an "hot spot" approach) or systems able of breaking the cost structure of "classical" cellular systems have to be found. In this respect, the integration of cellular systems with ad hoc multihop concepts seems to be a interesting "low cost" candidate. That is because, through this new networking paradigm, it is possible to enhance the capacity of a cellular system and/or extend its coverage without significantly increasing the expenditure level. Additionally, it is also worth considering that through the adoption of a *self-organizing* ad hoc networking, large part of the effort spent on network planning could be eventually saved.

The recent literature has been proposing a multitude of hybrid solution for civilian cellular systems. However, in the document [3] all these different implementations have been grouped in two main architectural designs:

1) Two-Layers Architecture groups together all the hybrid solutions that involve only two types of nodes: base stations and users terminals.

2) Three-Layers Architecture refers to the hybrid structures that are constituted by three types of nodes: base stations, user terminals and fixed relays.

The hybrid solutions belonging to the *Three-Layers Architectures* are provided with all the functionalities of a *Two-Layer Architecture*, and additionally employ fixed relays. This makes them able of meeting higher guarantees on performances [4]. On the other hand, the cost impact of these networks will depend on the level of expenditure necessary for building and maintaining these fixed relays.
Under this perspective, the solutions belonging to the *Two-Layer Architecture* group seems to represent the first step toward a feasible ad hoc wideband cellular system. In this case, the costs for allowing the multihopping will be shared between operators (small modifications at the base stations sites) and the users (purchase of ad hoc enabled terminals). This seems to have a large probability to happen, mainly due to the fact that there are already in the market "successful" ad hoc enabled products (e.g. IEEE 802.11 WLAN cards). For this reason, we focus in this paper on *Two-Layers Architectures*, considering these as an initial step toward more complex (and better performing) ad hoc multihop systems (e.g. *Three-Layers Architectures*).

A. Scenarios

The concepts described in this paper can be considered suitable to these two different scenarios:

1) In the first case we can consider a *legacy operator*, who is already operating a cellular network that is capable of providing universal coverage but with medium/low bit-rate. In particular, we consider that this operator is willing to upgrade its current network without significantly

increasing the order of magnitude of its expenditures. A way to achieve this goal would consist in finding a solution that could enhance as much as possible the network's efficiency, without radically changing its structure.

2) On the other hand, an *incumbent operator* is willing to enter a new market reducing as much as possible the duration of the network's *roll-out phase*. It is known that the cellular network business has considerably large barrier at the entrance, mainly consisting of base station deployment costs. Therefore, entering the market at low expenditure level and being able of providing, to the end users, the same quality of service provided by the competitors, would increase concurrence and lower the service prices.

B. Cost Model

Throughout this investigation, it is assumed a simple cost model in which the expenditures, for building and maintaining the whole infrastructure, are considered proportional to the number of base stations that are required for providing services (N_{bs}). Therefore, we define the following cost formula:

$$C^{A}_{infra} \simeq N_{bs} \cdot C_{bs} \quad (1)$$

In particular, C^{A}_{infra} represents the *absolute cost* of the infrastructure, and it is highly dependent on the cost of the base station sites/equipments (C_{bs}) in the specific time of the evaluation.

Assuming that the cost per base station, does not depend on a specific communication system, we can express the total cost of a system in a more efficient way: we can define the cost of an infrastructure as *relative* to the one of an infrastructure chosen as *reference system*. Thus, the cost comparison will be translated into a comparison on performances. In this way, the *relative cost* (C^{R}_{infra}) of a proposed system, in respect to a specific reference will be expressed in the following way:

$$C^{R}_{infra} \simeq \frac{N^{ref}_{bs}}{N^{sys}_{bs}} \simeq \frac{\lambda^{ref}_{bs}}{\lambda^{sys}_{bs}} \quad (2)$$

The mean for evaluating the cost advantages of a system will be ratio between the base station density, necessary for satisfying the service requirements, for both the reference and the proposed ad hoc solution.

The metric that will be used for evaluating the satisfaction of the requirements will be the average data rate per user. It is known that, in ad hoc networks, the average data rate achievable by the terminals, depends on the density of relaying nodes; this could have some significant impact on the performances (as it is possible to see in figure 4).

For this reason, we will quantify the impact of different user densities on the cost/performances trade-offs provided by our hybrid architecture.

II. Two Layer Architecture

The proposed hybrid ad hoc/cellular architecture consists of only of two kinds of nodes: user terminals and fixed base stations. In our design, we consider that information can be transmitted, between a terminal and a base station (in uplink or downlink directions), through a direct connection, or exploiting an indirect route consisting of terminal nodes located in intermediate positions (as shown in Figure 1). The latter mode of exchanging information is activated only if it leads to an end-to-end data rate improvement, and it is accomplished through a ”regenerate and forward” packet forwarding strategy.

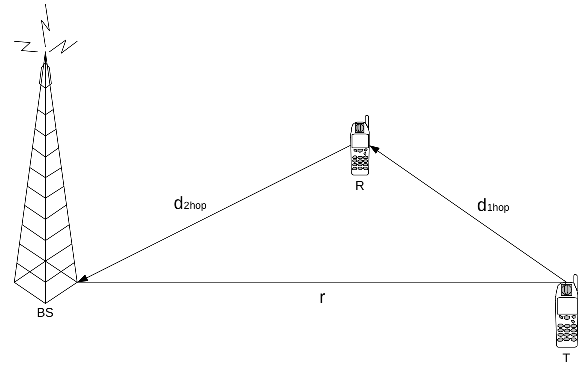

Fig. 1. Example of a 2-hops multihopping transmission

III. Investigation

The reference (SH) and the hybrid ad hoc multihop (MH) systems, described in this paper, are both assumed to be TDMA; in particular, we consider the same slot duration for both multihop and direct transmissions. Therefore, each of the links, constituting a feasible multihopping route, can only be activated for percentage of a time slot, and the total route duration is constrained to be equal to a time slot. The users are assumed to be distributed according to a two dimensional Poisson point process.. In order to quantify the average data rate per user we study the performances of a ”test” user placed in a specific location, and evaluate its average data rate. The averaging is analytically obtained through determining the geometrical locus in which a possible relay can give an advantageous data rate, and the probability of having at least one user in that area. The cost comparison is achieved through the evaluation of the base station density that are required for providing the same average user data rate in both systems.

According to equation (2), the goal of our investigation will be determining, for a specific service and in function of different user densities, the following ratio:

$$C^{R}_{infra} \simeq \frac{\lambda^{SH}_{bs}}{\lambda^{MH}_{bs}} \quad (3)$$

IV. System Model

In this section we describe the assumptions that have been made in the following parts of this paper; specifically, we decided to divide these assumptions into *system*, *environmental* and *service assumptions*.

A. System Assumptions

1) The reference and the hybrid ad hoc multihop systems, described in this paper, are both assumed to have the same bandwidth occupation and to be TDMA; in particular, we consider the same slot duration for both multihop and direct transmissions. Therefore, each of the links, constituting a feasible multihopping route, can only be activated for a percentage of time slot, and the total route duration is constrained to be equal to a time slot.

2) The cells, in which the cellular system is divided, are assumed to be hexagonal. Therefore, the distance between any pair of adjacent base station (reuse distance D) will be a function of the cell radius (r_{cell}) and the reuse factor (K):

$$D = \sqrt{3K} \cdot r_{cell} \tag{4}$$

3) Both systems are assumed to be *interference limited systems*. In particular, we assume that the uplink Signal to Interference level (SIR) can be described as:

$$\gamma = \frac{\frac{cP}{r_{cell}^{\alpha}}}{\sum_i \frac{cP}{d_i^{\alpha}}} \simeq \frac{\frac{cP}{r_{cell}^{\alpha}}}{6\frac{cP}{(D-r_{cell})^{\alpha}}} = \frac{(\sqrt{3K}-1)^{\alpha}}{6} \tag{5}$$

The interference power will be compute as the worst case obtainable at the cell border, and then assumed constant for the whole cell. Additionally, the terminals will always transmit with equal constant power.

4) The system efficiency (η) is expressed in bit/s/Hz/site. In this work, following [5], we assume $\eta = 0.45$ as the requirement on the minimum spectral efficiency to be provided by any *feasible system* (ad hoc or direct connection). Additionally, this requirement is considered meaningful only if, at the same time, the *user satisfaction* can be guaranteed. In this paper, we will consider that reaching some *service requirements* (the focus is on the achievable data rate per user) will imply providing satisfaction to the end users. In this case, given the operative bandwidth (B) of the system, its efficiency (η), and the number of active users per cell (N_u^a), the average data rate per user ($\overline{R_{user}}$) will be expressed in the following way:

$$\overline{R_{user}} = \frac{\eta B}{N_u^a} \tag{6}$$

This means that the capacity of a cell is equally shared among the active users.

B. Environmental Assumptions

1) The *user density* is assumed to be Poisson distributed with parameter $\lambda users/km^2$. This means that the average number of users per cell is $\overline{N_u} = \lambda \pi r_{cell}^2$.

2) Each of these users is assumed to be *active* with probability q, which represents the so called *activity factor*. Each of the active users will receive a time slot for exchanging data in both *Uplink* and *Downlink* directions.

3) The pathloss decay exponent is assumed to be equal for both mobile-to-mobile and mobile-to-base station communications; the propagation model is simply distance dependent and characterized by the following equation:

$$G(r) = c_0 r^{-\alpha} \tag{7}$$

In this work, we will focus on a deterministic propagation environment; thus, we will not consider the effects of the shadow and fast fading.

C. Service assumptions

We assume that these cellular networks are designed for providing a best effort service with equal requirements for the users. In particular this service is delay insensitive but an average data rate is guaranteed.

D. Definitions (Two Hops Network)

In this section we will introduce some definitions that will be used in the remaining part of the paper. These definitions assume the study of a multihopping system in which maximum two hops are allowed. The same concepts could be eventually extended for characterizing the study of systems with higher number of allowed hops; but this is beyond the scope of this paper.

Data Rate: given a source node (s) and a destination node (d), we define the data rate achievable in their connection as:

$$R(s,d) = B \cdot log_2(1+\gamma) \quad \textit{bits/s}$$

Where:

- B is the bandwidth assigned in the activation.
- γ is the SIR level at node d.

Rate Improvement (g): It is defined as the ratio between the data rate that is obtainable through a direct connection with the base station (single hop) and the one achievable through a multihopping route between the same source and destination. In particular, we will focus on two-hops routes, and $g \in \mathbf{R}$.

Feasible Two-Hop Route: In general, not all the possible two hops routes will lead to rate improvements ($g > 1$). In particular, assuming the notation of Figure 1, we will consider that the multihopping route leads to a data rate improvement if $\exists\ R$ so that:

$$\theta_1 \cdot R_{1hop} = g \cdot R_{dir} \tag{8}$$

$$\theta_2 \cdot R_{2hop} = g \cdot R_{dir} \tag{9}$$

where:

$$g > 1 \quad and \quad g \in \mathbf{R}$$
$$\theta_1 + \theta_2 = 1$$

In this specific context, we refer to θ_1 and θ_2 as the percentages of time slot in which, respectively, the first and the second link will be activated . In order to have a coherent comparison between a multihopping and a single hop systems, we will assume that the sum of the time slot shares has to be equal to one.

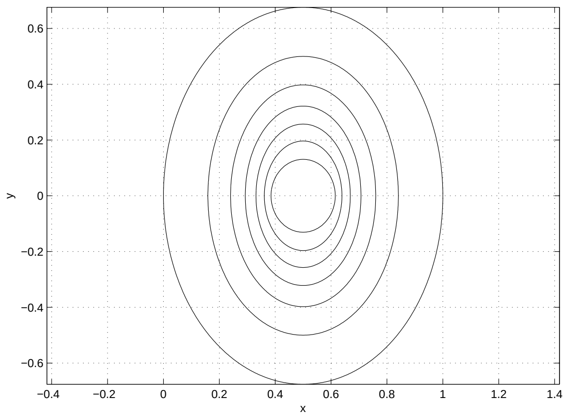

Fig. 2. Locus of 2 Hop Relays when the transmitting terminal is in position (1,0) (normalized radius). In this specifi c example, g varies with discrete steps between one and seven, passing from the outermost to the innermost curve.

V. Analytical Model

In this section we will introduce some of the derivation that has been performed in order to estimate the trade-off between cost and performances of these hybrid networks.

A. Relaying Locus for a Two Hops Rate Improvement

By using Shannon's definition of *achievable data rate*, and imposing the conditions represented by equations (8) and (9), we can write:

$$\begin{aligned}\theta_1 \frac{B}{K}\log_2\left[1+\gamma_{dir}\left(\frac{r}{d_{1hop}}\right)^{\alpha}\right] &= g\frac{B}{K}\log_2(1+\gamma_{dir})\\ \theta_2 \frac{B}{K}\log_2\left[1+\gamma_{dir}\left(\frac{r}{d_{2hop}}\right)^{\alpha}\right] &= g\frac{B}{K}\log_2(1+\gamma_{dir})\end{aligned}$$

Setting a reference system (as indicated in Figure 1) with BS at $(0,0)$, the *originating terminal T* at $(r,0)$ and the *relaying terminal* at (x,y), we can write that:

$$\begin{aligned}d_{1hop} &= \sqrt{(x-r)^2+y^2}\\ d_{2hop} &= \sqrt{x^2+y^2}\end{aligned}$$

This leads to find the generic equation of the relaying locus:

$$\begin{aligned}&\frac{1}{\log_2\left[1+\gamma_{dir}\left(\frac{r^2}{(x-r)^2+y^2}\right)^{\frac{\alpha}{2}}\right]}+\\ &+\frac{1}{\log_2\left[1+\gamma_{dir}\left(\frac{r^2}{x^2+y^2}\right)^{\frac{\alpha}{2}}\right]}=\\ &=\frac{1}{\log_2\left(1+\gamma_{dir}\right)^{g}}\end{aligned} \tag{10}$$

A representation of the locus, for a specific case of study can be found in Figure 2.

B. Vertical Axis

Because of the fact that the locus is symmetrical in respect to the point $(\frac{r}{2},0)$, we can easily determine its maximal (minimal) vertical extension.

In order to compute the vertical axis, we will consider the fact that at the maximum y point (according to figure (1)) the distances d_{1hop} and d_{2hop} will be equal. This will imply that the data rates obtainable in each of these two paths will be the same, and that the time shares θ_1 and θ_2 will have equal duration.

Using the planar geometry that is shown in figure (1), we can write the following system:

$$\begin{aligned}x &= \frac{r}{2}\\ y &= \sqrt{{d_{1hop}}^2-\left(\frac{r}{2}\right)^2}\end{aligned}$$

Substituting the value expression for d_{1hop}, we can determine the value of y:

$$y = r\cdot\sqrt{\left(\frac{\gamma_{dir}}{\left(1+\gamma_{dir}\right)^{2\cdot g}-1}\right)^{\frac{2}{\alpha}}-\left(\frac{1}{4}\right)} \tag{11}$$

C. Maximal Multihopping Data rate (Two Hops Case)

Equation (11) represents a decreasing function of g, and it is constrained to have positive sign. By determining the conditions in which this equation has values smaller or equal to zero, we can determine the maximum achievable data rate improvement as function of α and γ_{dir}:

$$g_{max}(\alpha\ ,\ \gamma_{dir}) \leq \frac{\log_{10}\left(1+2^{\alpha}\cdot\gamma_{dir}\right)}{2\cdot\log_{10}\left(1+\gamma_{dir}\right)}$$

In particular, due to the symmetry of the problem, we know that this maximum value is only reachable when the relay node is in position $(\frac{r}{2},0)$. Thus, by setting $g_{max}(\alpha\ ,\ \gamma_{dir}) \leq 1$, we are able to determine the condition that makes the locus collapsing in the point $(\frac{r}{2},0)$, or becoming composed by purely imaginary points. In these cases, there will not be any gain from selecting a multihopping route. That condition can be expressed as:

$$\gamma_{dir} \geq 2^{\alpha}-2 \tag{12}$$

It is important to notice that this value is independent of r.

D. Expected Data rate

Let us assume that a *sample* terminal is located at a distance r from the base station (position $(r,0)$). In order to achieve any data rate improvement, through multihopping, it is necessary that an eventual relaying terminal is located within the *geometrical locus* (equation 10) described by $k=1$ ($L_1(r)$). Now, for any position $(x,y)\in L_1(r)$, the generic data rate improvement of each hop, can be expressed as a function of the data rate achievable on direct communication, introducing some coefficients α and β, functions of the specific positions of the relay and transmitting terminal. This is translated in the following set of equations:

$$\begin{aligned}R_{1hop}(x,y,r) = \alpha(x,y,r)R_{dir}(r)\\ R_{2hop}(x,y,r) = \beta(x,y,r)R_{dir}(r)\end{aligned}$$

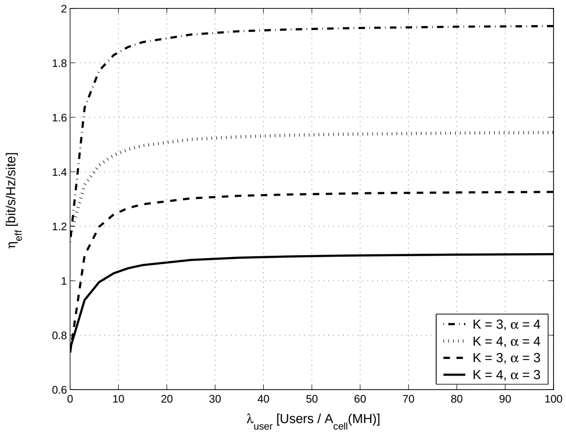

Fig. 3. Comparison between different achievable η (refers to equation (16)) for systems with $B = 5MHz$.

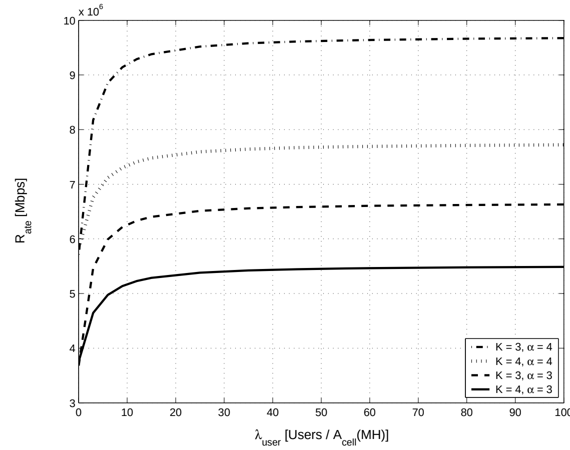

Fig. 4. Comparison between different $\overline{R_{ate}}$ (refers to equation (17)) for systems with $B = 5MHz$.

This system of equations is still constrained by:

$$R_{1hop}(x,y,r)\cdot\theta_1 = R_{2hop}(x,y,r)\cdot\theta_2 = R_{dir}\cdot k$$
$$\theta_1+\theta_2 = 1$$

Therefore, we obtain the following expression for the data rate improvement:

$$g(x,y,r) = \frac{\alpha(x,y,r)\cdot\beta(x,y,r)}{\alpha(x,y,r)+\beta(x,y,r)} \tag{13}$$

Now, we are able to evaluate the expected achievable data rate as a function of the distance from the base station. This is defined as:

$$\begin{aligned} R_{ate}(r) &= \left(1-e^{-\lambda A_{L_1(r)}}\right)\cdot \\ &\cdot \iint_{(x,y)\in A_{L_1(r)}} g(x,y,r)R_{dir}(r)\frac{dxdy}{A_{L_1(r)}} + \\ &+ \left(e^{-\lambda A_{L_1(r)}}\right)\cdot R_{dir}(r) \end{aligned}$$

In this formula $A_{L_1(r)}$ refers to the area of the locus with improvement equal to one, and $\left(1-e^{-\lambda A_{L_1(r)}}\right)$ represents the probability of having at least one user in that relaying locus. It worths mentioning that, this formula leads to a pessimistic estimation of the data rate achievable at a distance r from the base station. This depends on the fact that, according to our model, we randomly select the relaying node among all the possible terminals that are contained in the locus $L_1(r)$.

E. Reference System and Fair Allocation of Slot Durations

All the active terminals are assumed to use the same constant power level for their transmissions. Thus, a terminal that is closer to the base station will have access to larger data rates. In this section, we want to complete our description of this Two-Layer system addressing the problem of assigning an equal amount of resources to all the users in the network. The equation that we propose for ruling this *fair resources assignment* is the following:

$$s(r)\cdot R_{ate}(r) = c\cdot\frac{2r}{r_{cell}^2} \tag{14}$$

In this case, $s(r)$ represents the percentage of the frame duration that is assigned for transmissions originated at a distance r from the base station.

In particular we define:

- $\int_0^{r_{cell}} s(r)\cdot dr = 1$,
- c is a proportionality constant,
- $pdf(r) = \frac{2r}{r_{cell}^2}$ is the user density function.

The left-hand side of equation (14) represents the cumulative amount of information that can be delivered to the base station from all the terminals located at distance r. Through this equation, we are forcing this amount of information to be proportional to the number of user that are statistically located in position r.

Due to the fact that we are working with normalized frame duration, the average data rate achievable in a single transmission (*cell rate*) can be expressed in the following way:

$$\overline{R_{ate}} = \int_0^{r_{cell}} s(r)\cdot R_{ate}(r)\cdot dr \tag{15}$$

It is important to underline that this quantity is relate to the system efficiency by the following formula:

$$\eta(\lambda) = \frac{\overline{R_{ate}}(\lambda)}{B} \tag{16}$$

An example of this quantity is shown in Figure 3.

Using equations (14)-(15), and the definition of $s(r)$, we are able to compute the average data rate achieved by the end users:

$$\overline{R_{ate}} = \frac{1}{\int_0^{r_{cell}} \frac{1}{R_{ate}(u)}\cdot\frac{2u}{r_{cell}^2}\cdot du} \tag{17}$$

F. Relative Cost

In this section we describe the procedure for estimating the relative cost expressed by equation (3). Because of the fact that the two systems (multihopping and singlehopping) are *interference limited*, we can set, without loss of generality, the radius of the multihopping system ($r_{cell}(MH)$) to one:

$$r_{cell}(MH) = 1 \tag{18}$$

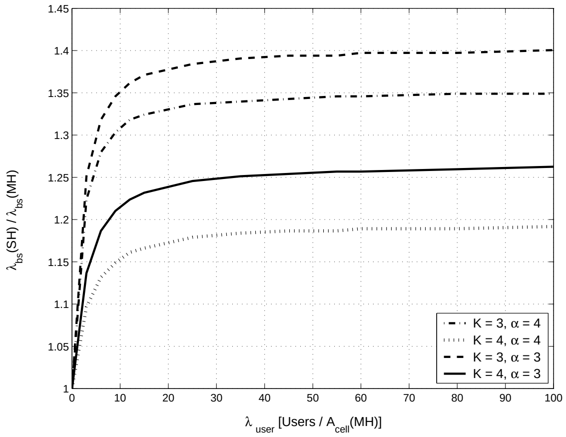

Fig. 5. Base Station density reduction through a multihopping system (numerical solutions of equation (22)) for systems with $B = 5MHz$.

In this context, we are interested in determining the *information density* (I_d) of the two systems; for a given system, this quantity can be defined as:

$$I_d = \frac{\overline{R_{ate}}}{\pi \cdot r_{cell}^2}[bps/km^2] \quad (19)$$

According to the specific systems under evaluation we know that the cell rate for the single hop system $R_{ate(SH)}$ can be computed directly from equation (17), considering, in place of $R_{ate}(u)$, Shannon's capacity formula.

On the other hand, the multihopping cell rate $R_{ate(MH)}$ can be obtained by following the whole procedure described in the previous section, and it is shown in Figure 4. In particular, according to equation (18), we know that for the multihopping systems we can write:

$$I_d(MH) = \frac{\overline{R_{ate}}(MH)}{\pi \cdot r_{cell}^2(MH)} = f(\lambda) \quad (20)$$

The relative cost can be obtained by numerically evaluating, for all the values of $f(\lambda)$, the specific value of $r_{cell}(SH) = \widehat{r_{cell}(SH)}$ that leads to equal *information densities* in both systems. This is equivalent to solving, for every $\widehat{\lambda}$ the following equation:

$$f(\widehat{\lambda}) = \frac{R_{ate}(SH)}{\pi \cdot \widehat{r_{cell}}^2(SH)} \quad (21)$$

The base station density is the inverse of the area covered by a single base station. In this way, we can determine the relative cost, as defined in equation (3), by finding the following function of λ:

$$\frac{\lambda_{bs}^{SH}}{\lambda_{bs}^{MH}} = \frac{R_{ate}(SH)}{\pi \cdot f(\lambda)} \quad (22)$$

This relative cost function is shown, for different environments and reuse factors, in Figure 5.

VI. Discussion

In order to interpret the results that are shown in Figure 3-5, it is necessary to take into account the implications of equations (5) and (12). It is clear that multihopping is not always beneficial. In table I, are summarized the values of maximum allowed SIR (γ_{max}) and feasible reuse patterns (K) that leads to benefit from multihopping (when α varies between 2.5 and 5). Additionally, we notice that $K = 7$ is never a feasible reuse pattern for any $\alpha \geq 2$. In all the presented solution, it is possible to notice a specific breakpoint value, for the user density, after which there are no extra improvements. This represents a sort of *critical mass* for ensuring almost maximal performances to the system. From these results seems reasonable to assume this critical user density equal to ($\lambda \simeq 15$) [users/cell]. After this point the additional improvements on system performances are contained within 5 percent.

TABLE I
Feasible Reuse Factors

α	γ_{max}	K
2.5	5.62 dB	$1-3$
3	7.78 dB	$1-3-4$
3.5	9.68 dB	$1-3-4$
4	11.46 dB	$1-3-4$
4.5	13.14 dB	$1-3-4$
5	14.77 dB	$1-3-4$

From this consideration we can extrapolate an initial deployment guideline: the largest multihopping contributions can be obtained if the multihop network is dimensioned to provide an average of at least fifteen relaying users per cell.

Additionally, we want to underline that, solutions capable of providing larger spectral efficiency improvements (Figure 3), in respect to the reference system, are also leading to larger cost savings (Figure 5). As an example of this, we can consider the case study with $K = 3$ and $\alpha = 3$: this system shows a spectral efficiency improvement of about 85 percent, and provides the largest cost savings, if compared to its referenced single hop system. At the same time, having larger absolute spectral efficiency will make it possible to accommodate a larger average number of active users (requiring all the same average data rate), and this will increase the network's revenues.

From the results of Figure 4 we notice that when the value of α is large, the *cell rate* that will be shared among the active users increases; additionally, for a fixed α the revenues of the network increase for decreasing reuse factors. The adoption of small reuse factors in the network planning is also supported by the cost comparison of Figure 5, where it is shown that smaller reuse factors lead to lower base station densities.

Results concerning the study case with $K = 1$ are not presented in this paper. This is done because, in the case of *global frequency reuse*, the interference model described by equation (5) is likely to be inaccurate.

VII. Conclusions

In this paper we have shown a novel approach to the dimensioning problem of an hybrid ad hoc/cellular system. The simple analytical model that has been used in the comparison between single hop and multihop networks has made it possible to describe the conditions in which multihopping leads to substantial advantages.

Some general guidelines about the network planning has also been described and supported by results on specific test cases. Small reuse factors, and the possibilities of having, at least, a *critical mass* of about 15 relaying users per cell, are the operating conditions in which, a system capable of activating two-hops transmissions, is performing at its best: the spectral efficiency of a multihop network can almost double the one achievable by its equivalent single hop network (e.g. the study case with $K = 3$ and $\alpha = 3$ of Figure 3).

This, under the perspective of an *incumbent operator*, might leads to a better usage of its current single hop system with a low expenditure level. On the other hand, a *greenfield operator* that decides to adopt a multihopping-compatible approach, will be able to lower the total expenditures for building its network (its main entrance barrier), and the duration of the *roll-out phase*. In particular, from our numerical evaluation we see that is possible to achieve a maximal cost reduction close to forty percent (see the study case with $K = 3$, $\alpha = 3$ in Figure 3).

Some issues, concerning the presented model, remain still open; among these the evaluation of networks capable of sustaining larger degree of multihopping, the introduction of a route selection strategy focused on performance maximization, the evaluation of the high reuse case ($K = 1$) and the use of a more realistic propagation model will be the object of future studies.

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