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# Capacity Enhancement Using Intelligent Relaying for Future Personal Communication Systems

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## Abstract

*This paper highlights the key benefits of using Intelligent Relaying (IR) for future personal communication systems. IR is a technique that incorporates direct mobile to mobile communication, allowing end-to-end connectivity in a network to be implemented via a number of short hops. A mobile can in theory reach any destination by transmitting only as far as its closest neighbour, bringing potential benefits such as an overall reduction in transmit power, and the possibility of increased capacity. In addition, the self-organising nature of the network may reduce the need for network planning and basestation infrastructure. Disadvantages include an overall increase in complexity, and the problem of a particular user's terminal being used for the benefit of others.*

*Results are presented that quantify the gains in capacity that can be brought about by the lower levels of interference due to reduced transmit power throughout a sample test network. A simulation platform is described which uses IR as an enhancement to a hybrid TDD/CDMA air interface similar to the UTRA TDD mode. It is shown that capacity can be increased, although this capacity gain is dependent on there being a sufficient number of users available to act as relays.*

## 1. Introduction and concept of Intelligent Relaying

Intelligent Relaying (IR) is a technique in which any mobile station (MS) is able to re-transmit data on behalf of another mobile. This means that in a cellular network, the process of communication between a mobile and a basestation may be accomplished using a series of short mobile to mobile hops, rather than a single mobile to basestation transmission. This process is illustrated in Figure 1.

The changing positions of the MSs, allow them to form an adaptive overlay of relays that provide coverage in addition to that directly from the basestation.

The motivation for implementing relaying is to reduce the total power required by the network to support a certain number of calls. This reduction in power level will extend the battery life of users' terminals and, more importantly, may allow an according increase in the capacity.

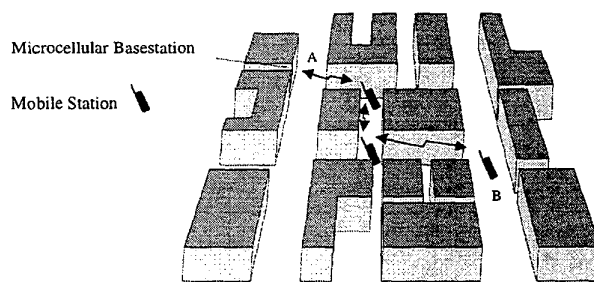


Figure 1. Intelligent Relaying in a microcellular environment.

In general, enabling IR implies an increase in the overall complexity as well as issues such as the draining of users' battery life for the benefit of others in the network. The purpose of this paper is to present the advantages and disadvantages of IR and to see if the gains in capacity are considered adequate to outweigh the problems. This is achieved by analysing the operation of relaying within a framework similar to the UTRA-TDD mode implemented for UMTS [6]. A particular type of IR known as Opportunity Driven Multiple Access (ODMA) is already under consideration for 3rd Generation Systems [1], as an extension to the UTRA TDD mode.

## 2. Advantages and disadvantages of Intelligent Relaying

### 2.1. Advantages

The main perceived benefit of implementing IR is the possibility to increase capacity by reducing transmit power. Typically, a route between an MS and BS which comprises a number of short hops, can be accomplished with a lower aggregate power deployment than one which requires a direct path. This general lowering of powers leads to reduced interference levels; as the chief factor which limits the capacity in a CDMA network is the amount of interference, a corresponding capacity increase is expected when IR is implemented. The power level reductions also permit an increase in the users' battery life, and can allay fears regarding health risks.

It is also possible to use relaying to extend coverage into areas not covered by the conventional cells and into areas that suffer poor coverage within cells [5]. This is achieved by forming a relaying connection to an already connected mobile, i.e. one which does not suffer the same disadvantageous propagation characteristics.

Traditionally, operators have invested resources into planning techniques which model the performance of their networks in a given physical environment. Sophisticated planning tools have been developed, which can be used to predict coverage and capacities across the network area. However, such tools are only as good as the information that is provided to them, and may require detailed topographical knowledge of the environment. Whilst this is feasible for simple outdoor coverage, the prediction of coverage indoors, which may be achieved via a variety of propagation mechanisms, is more challenging. Additionally, it is impractical to perform surveys with sufficient detail to provide enough information to a simulation tool. For these reasons, there has been increasing interest in so-called "self-organising" networks [8], which are able to adapt their own behaviour in order to maximise the performance of the network. Self-organisation also allows additional infrastructure to be added to a network without extensive re-optimisation.

### 2.2. Disadvantages

The main disadvantages of the technique concern the concept of individual users' terminals being used for the benefit of others, and the general level of complexity in the network required to support IR.

Under certain circumstances, it would be possible for a particular user to be denied access to the network because:

1. all the resources of the user's terminal are currently being used to relay data on behalf of others

2. the battery of the user's terminal has been exhausted due to relaying data

In practice, these problems could be mitigated by strategies such as offering credit to network subscribers who choose to allow their terminals to relay, or by implementing restrictions on the amount of traffic that a particular terminal is permitted to relay.

The complexity of the technique, particularly concerning the additional processing required to assess and establish relay routes, is also a disadvantage. With the intelligence required to manage the network distributed amongst the mobiles, rather than performed centrally at a base station, there will potentially be a large signalling overhead required to disseminate the network control information between nodes. This additional signalling may also increase timing delays for end to end transfer of data.

## 3. Implementation and simulation of Intelligent Relaying

### 3.1. Implementation issues

This paper concerns the suitability of IR for use with the UTRA TDD mode. The technique is assumed to be particularly applicable for such time duplexed systems, as correlation of the end-to-end paths for uplink and downlink can be exploited to simplify the selection of relay links.

Previous results [5] based on path loss studies, have demonstrated that IR can bring an average reduction in transmit power for the network of 21dB, which should manifest itself as a corresponding increase in the network capacity. The aim of these studies is to estimate the number of users that can be supported simultaneously, by considering a full implementation of IR, including the allocation of resources, power control and interference measurement.

One challenge for implementation of IR for an UTRA TDD mode system, is the required technique to reduce interference between individual transmissions. The capacity of CDMA is limited by interference levels, and conventional CDMA networks must implement strict power control to ensure that all transmissions are received by the base station at the same power level [9]. When IR is permitted in a CDMA network, transmissions are no longer made (and power controlled) exclusively to a base station, and therefore intra-cell interference levels may increase. Two possible solutions to this problem are:

1. to use different time-slots to prevent interference between users
2. to ensure that all power levels are minimised

Option 1 implies that the network must have enough intelligence to re-allocate resources due to the mobility of users. This intelligence may be located centrally (e.g. at a basestation), or distributed among the network nodes. Option 2 is a less intelligent method, resources being allocated to links on a more random basis, in the hope that the transmitted power levels will be so low so as not to cause excessive interference to other users. In either case, each individual link in the network must be power controlled at the receiving end to ensure the minimum power necessary is radiated.

Joint detection techniques are not considered, as the technique is currently available only at basestations. In the IR network, the problem of intra-cell interference is of concern equally at the mobilestations.

### 3.2. Theoretical gains

An UTRA TDD mode network (without an IR implementation) would have a theoretical capacity for each time slot derived from the classic formula given by Equation 1, assuming that each mobile can be power controlled correctly at the basestation [4].

$$\frac{E_b}{N_o} = \left[ \frac{1}{(N-1)} \right] \alpha \quad (1)$$

where  $\alpha$  is the CDMA spreading factor for the required service,  $E_b/N_o$  is the energy per bit divided by the noise power and  $N$  is the number of users.

Applying Equation 1 for an 8kbit/s service (e.g. for voice) with a target value for  $E_b/N_o$  of 6dB and the maximum spreading factor of 16 gives a maximum theoretical capacity of 5 users/slot. For a conventional (i.e. non-relaying) implementation, the 14 available time slots therefore allow a total system capacity of 75 individual links per frame, each link being used for either uplink or downlink. Simulations of the complete UTRA implementation, including features such as joint detection, have reported actual uplink and downlink capacities of 53 and 57 erlangs/cell respectively [3].

The consideration of relaying in the TD-CDMA network implies that each individual mobile to basestation connection requires more than a single resource (i.e. multiple timeslots). The concept of uplink and downlink becomes more difficult to consider as, within a single timeslot, different users can be using the same resource to communicate in different directions.

Crucially, each one of these greater number of links is no longer power controlled for optimum reception at the receiving node. The interference thus caused is analogous to inter-cell interference for the non time-slotted CDMA case. This problem is illustrated in Figure 2, where each individual mobile-mobile or mobile-basestation link is given a

unique number and either a U or L suffix to signify whether the transmission is going towards or away from a basestation. The slot allocation demonstrates where possible interference may occur; for example, the resource allocation demonstrated in Figure 2 will only work if the signals associated with the links denoted 3U and 6U are sufficiently low so as not to interfere with each other.

The exact interference levels are therefore highly sensitive to the positions of all the mobiles in the network, which is the motivation for implementing a series of simulations in which the users are deployed randomly.

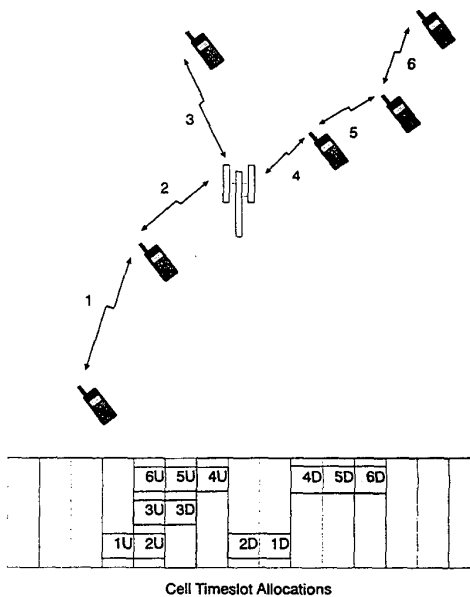


Figure 2. Allocation of timeslots within a cell

### 3.3. Simulations of an ad-hoc Intelligent Relaying network

A series of simulations have been performed on a network incorporating IR, an air interface similar to that defined for the terrestrial portion of UMTS (UTRA) has been investigated [2].

A mobile-mobile path loss model developed at the University of Bristol has been used[5], as conventional cellular models which describe the path loss between elevated basestations and mobiles at street level are not considered appropriate. The model has been validated for measurements in the 2.1GHz frequency band [7], over short distances and using antennas mounted at low heights (e.g. < 2m above street level).

The simulator operates by placing a predefined number of MSs randomly within the service area, allowing the re-

quired number to connect to a basestation, and then testing their behaviour. When a call is set up, the MS will follow the procedure of selecting a relay route, resources being allocated by the network as required. During each call, the MS will measure and record the SIR (Signal to Noise Ratio) and received signal strength for each time slot, and adjust the transmit power, as required. Calls will fail if the relevant MS is required to increase its output beyond its maximum limit in order to maintain an acceptable  $E_b/N_o$ .

Relay routes are selected from a pool of candidates. Each mobile measures path loss to other MS in the network, and from this compiles a list of 10 neighbours. These neighbours are then used as potential nodes in compiling relay routes. From the list of relay routes available, the one offering minimum aggregate expended transmit power is selected.

The second stage in the call set-up procedure is the allocation of radio resources. Each call requires sufficient timeslots at the originating node, the basestation and the intermediate relay points. If timeslots are not available, then the next best relay route will be used. Single timeslots are allocated at the originating MS and at the BS, whilst a pair of time-adjointing slots is allocated at each relay node, each slot providing communications in one direction. The use of multiple timeslots to increase the data is not currently considered; higher data rate services are considered by increasing the spreading factor only.

Time slots are allocated to each individual link on an ad-hoc basis. No attempt is made to minimise interference by allocating resources based on the geographical positions of any other mobiles. This allows an assessment of the random problems of intra-cell interference to be measured, as discussed previously. Due to the random allocation of timeslots within a frame for a particular service, when calculating the interference values, an average of the transmit power across the frame is used.

A summary of the simulation parameters used is given in Table 1.

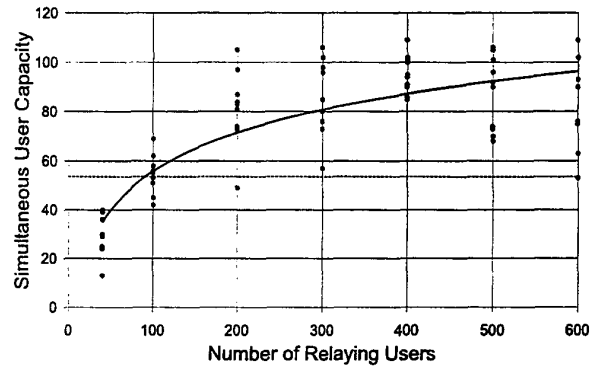
Frequency	2.4 GHz
Target $E_b/N_o$ per link	6 dB
Receive Sensitivity	-102 dBm
MS Power Output Range	$\leq 30\text{dBm}$ $\geq -40\text{dBm}$
Spreading Factor Range	1-16

**Table 1. Simulation Parameters**

The test network comprises a single basestation and a number of mobiles that are deployed in a  $1\text{km}^2$  square grid with the basestation at its centre.

## 4. Results

The results presented in Figures 3–5 demonstrate the number of calls that can be supported in the test scenario; voice and higher data rate services have been investigated. The benefits of relaying are expected to become more apparent as the total numbers of users increases, and so investigations have been carried out with varying user densities. Each simulation has been repeated a number of times, and an average result taken.



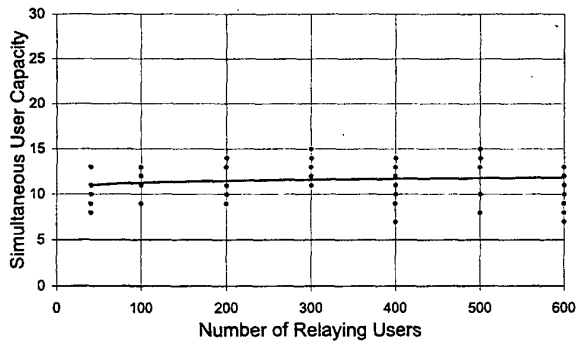
**Figure 3. Calls possible for 8kbps data voice service**

Figure 3 shows the number of simultaneous relaying users that can be supported if the spreading factor is 16, i.e. the maximum permissible. In this scenario, all the users require an 8kbps/s voice service. The dotted line on the graph represents the previously cited simulated capacity for UTRA TDD mode [3].

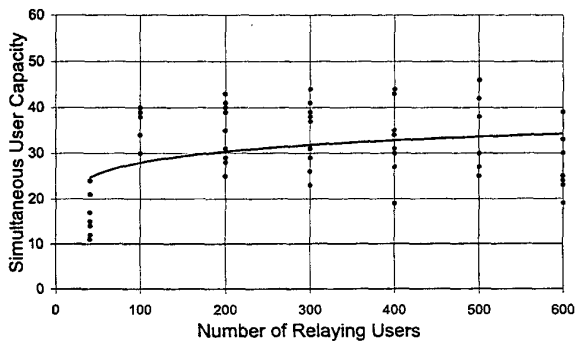
As can be seen from the graph, provided that the number of deployed users available to relay exceeds approximately 80, the capacity can be increased with respect to the non-relayed TD-CDMA case. As the number of relays available increases, the capacity also goes up and tends towards an absolute maximum level. This absolute level is a limit imposed by the interference levels in the network. In this case, the maximum level is at approximately twice the simulated capacity for non-relayed UTRA TDD mode.

Figure 4 shows the number of simultaneous users that can be used if the spreading factor is reduced to 1, representing the fastest data rate possible without permitting multiple timeslots to be used. In this case, the increased interference caused by the lower spreading factor means that the absolute maximum capacity is reached for a lower user density.

Figure 5 demonstrates a service scenario using a mixture of services from the two previous sets of results. To achieve



**Figure 4. Calls possible for 128kbps data service**



**Figure 5. Calls possible for mixed voice/data services**

this, 10 higher data rate call are initially established, all further attempted calls use the voice service parameters. As expected, the shape of this curve shares the characteristics of the pure voice and data curves. The interference caused by the calls using higher data rate services restricts the number of additional calls that can be supported.

In each of the sets of results, the individual data points on the graphs represent the results of independent simulations, whilst the curve is a calculated trend-line. The wide variance of results show that the capacity gains are dependent on the particular configuration of users at any point in the simulation. Typically, the actual capacity value could be exceeded or diminished by 20% of the plotted average.

## 5. Conclusions

The results demonstrate that for a TD-CDMA network using IR, the number of simultaneous users that can be supported is higher than the theoretical pure power-controlled

CDMA case, provided that the network has a sufficient number of users to act as relay nodes. A comparison with previous UTRA TDD mode simulations has shown an approximate doubling of user capacity. Implementation of joint detection will allow capacity gains to be exploited further.

As more users are added to the network, providing additional relay points, the lengths of the individual relay paths shorten and so more power can be saved per hop. More relay nodes can also lead to a diversity of relay routes, meaning there are more options for transmit power to be minimised. The capacity gain tends towards an absolute maximum, however, as the increased number of active relays causes additional interference. The actual capacity gain is dependent on the location of relays; so in order to minimise the amount of uncertainty caused by the random location of mobiles, a network operator may choose to deploy fixed relay nodes at certain points in the network.

The disadvantages of IR are the added complexity needed to support the technique, and the concept of using user's battery power for the benefit of others.

## 6. Acknowledgements

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