The Application of Intelligent Relaying to Urban Microcellular Telecommunication Networks

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Abstract – In this paper, the feasibility of applying a novel concept, namely Intelligent Relaying (IR) to urban microcellular wireless networks is discussed. Simulation results show that IR has significant effects on reducing the pathloss experienced in such networks. Results concerning link pathloss distribution showed that while the highest frequency of savings lie in the range from 0 to 4dB, IR reduces the maximum pathloss by up to 15dB, and the average pathloss by 10dB. In addition, the maximum pathloss is reduced from 165dB to 150dB.

1. Introduction

The concept of Intelligent Relaying (IR) permits direct communication between mobile stations (MSs), consequently, signals from a base station (BS) can be relayed through other MSs to reach the served MS. This technique offers potential improvements in network capacity, coverage, range and power efficiency, as well as potential cost savings owing to the installation of fewer BSs.

The IR concept was first proposed in the 3rd Generation Partnership Project (3GPP) UMTS recommendations [1], originally for application to macro-cellular coverage scenarios. Harrold and Nix later extended the application of IR methods to urban microcellular wireless networks [2].

In this paper, we describe the simulation of an urban microcellular wireless network environment and investigate the effects of implementing IR in such a system.

2. Pathloss Models

This section describes the modelling techniques used to simulate IR in an urban environment. The investigations were undertaken using a Java-based computer simulation model, namely IRSim. The IRSim application was originally created by Aldis [3], and was modified to produce the results described in this paper. IRSim is a dynamic simulation of a microcellular network. It employs a Manhattan-style urban environment and can control MS location and call status, and is able to route calls through relaying MSs.

The effect of street corners in an urban microcellular environment is one of the primary factors affecting the pathloss and hence performance of a mobile network. Moreover, the incorporation of corner effects into the pathloss model will greatly affect the performance of IR in this environment. Consequently, the General Recursive microcellular method [4] is employed when considering propagation down streets. However, when propagation takes place around multiple corners, then the dominant propagation mechanism is over the rooftops. In this case, use of the COST Walfisch Ikegami model [5] is appropriate.

General Recursive Method for Microcellular Path Losses

The General Recursive Method (GRM), described by Berg in [4], combines empirical and physical propagation models. It works on the principal that non-line-of-sight (non-LOS) propagation introduces effective sources which can be used as a construction for wave propagation. The method breaks the path down into a number of segments, with each subsequent segment being affected by the effects of previous segments. The GRM was simplified to reduce computation and to permit understanding of the pathloss characteristics along a given path in an urban environment. For the simulations conducted in this work, the environment was constrained to a Manhattan grid, leading to the approximation that all corners can be represented by right-angle turns. Because the street widths are small compared to the lengths between building blocks, in reality, the angles in such an environment do not deviate significantly from 90 degrees.

COST Walfisch Ikegami - Over the Roof-tops Model

Where there is not a simple LOS path between antennas, a significant propagation path is that over the rooftops. An empirical pathloss model was developed during the European COST 231 project [5], using measurements taken from Stockholm, Sweden:

$$PL_{dB} = 24 + 45\log(d + 20) \qquad \textbf{(1)}$$

where d is the shortest geographical distance between the two ends of the link. Additional parameters may be added to account for different building heights and types of roofs etc.

3. Pathloss Savings

In this section, the pathloss savings achieved by applying IR to an urban microcellular network are analysed. In order to produce a quantitative estimate of the power savings that could be achieved by IR, the distribution of pathloss savings was examined. Using the data from the simulation, the probability distribution function (PDF) of pathloss savings was plotted. These simulations were performed for 30, 60 and 120 MSs.

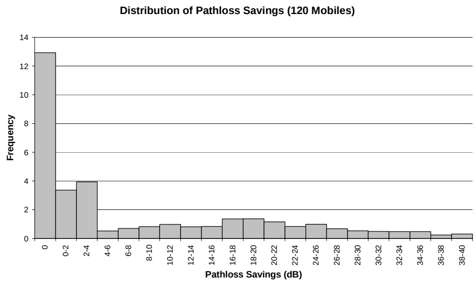

Figure 1: Distribution of Pathloss Savings (120 MSs)

Figure 1 shows the link savings in a simulation having 120 MSs categorised into 2dB bins, and their corresponding frequency of occurrence. The first bin represents links for which there is zero pathloss saving. It can be seen that there are a high proportion of links for which there is zero pathloss savings, i.e., these correspond with MSs for which the most efficient route does not go through a relaying node.

To understand the PDF in greater detail, the zero saving links were excluded, and the graph plotted again in Figure 2.

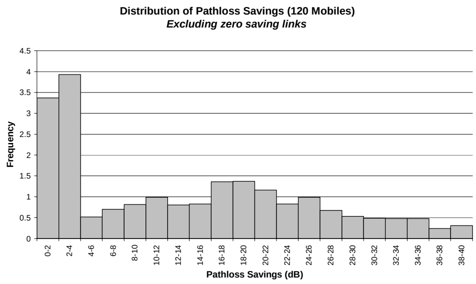

Figure 2: Distribution of Pathloss Savings (120 MSs), Excluding Zero Saving Links

Figure 2 shows that links with a path saving of 0-2dBs and 2-4dBs are the most frequent. Above 4dB, the frequency of pathloss saving falls markedly. The distribution is then fairly constant, rising to a peak at savings of 18-22dBs, before falling to zero above 36dBs.

Unfortunately, these graphs indicate that the savings gained by IR are frequently rather small, i.e., less than 4dB. Furthermore, when pathloss savings are greater than this, the effects of IR are fairly uniform for savings from 4dB to 36dB.

At first glance it appears unlikely that IR would be worth implementing considering the low and/or infrequent pathloss reductions. However, it is evident that some large savings are available, and in an interference limited system such as code division multiple access (CDMA), there may still be some capacity benefits available owing to the elimination of powerful interference sources. Never the less, it is likely that any IR system would selectively route through a relaying node, only if the savings were large enough to warrant the additional power consumption of the relaying MS and the extra latency caused by relaying.

Use of Relaying Nodes

The previous results suggest that much of the savings brought about by IR lie in the range of 0-4dB. At these levels of savings, the costs of implementation as well as the additional latency may not warrant the wholesale application of IR in a mobile network. However, the distributions also illustrate that larger savings are present in the system, albeit at lower frequencies.

One possible solution to the problem of low savings and high implementation costs is the use of relaying nodes or 'IR nodes', placed at strategic positions where they would be most effective. This has several benefits:

1. Low cost as relaying only needs to be implemented in the IR nodes rather than all MSs.
2. High pathloss savings due to strategic placement of the IR nodes, e.g., at street corners.
3. Easier routing algorithms as IR nodes would not be mobile.

An approximate calculation shows that it would be possible for the average IR node to provide significant pathloss savings in the range of 30dB. Taking the standard 230m by 230m Manhattan block used in the simulations, a link of total length 345m, comprising of a 230m segment and a 115m segment separated by a corner gives rise to a pathloss saving of 32.7 dB. This approach could potentially give more significant power savings at lower implementation costs.

4. Link Pathloss Distribution

While the distribution of pathloss savings discussed in the previous section shows the spread of individual path loss reductions as a result of IR, it does not link these savings to overall pathloss. This section makes the connection between pathloss savings and actual pathloss distribution, showing which links the savings shown in the previous section are associated with, and hence discover how IR changes the distribution of pathloss in the overall system. Simulations were run with 60, 120 and 240 MSs and the overall distribution of pathloss with and without IR was observed. Again, the 120 MS case will be taken as an example.

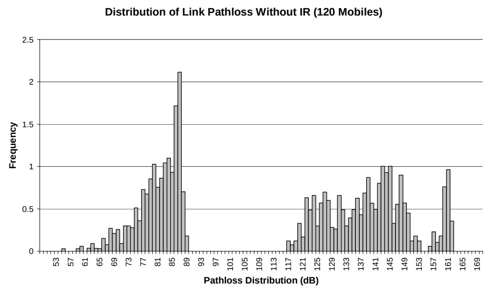

Figure 3: Distribution of Link Pathloss Without IR (120 MSs)

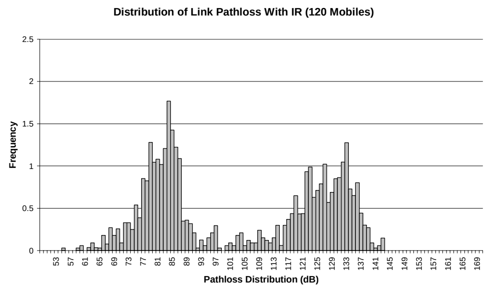

Figure 4: Distribution of Link Pathloss With IR (120 MSs)

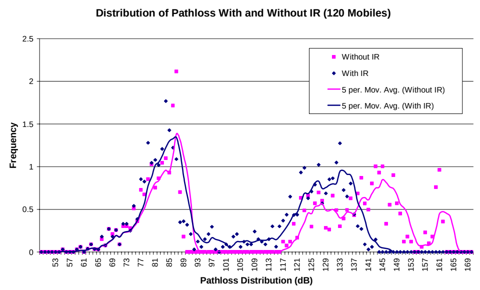

Figure 5: Comparison of Pathloss Distribution With and Without IR (120 MSs)

Figure 3 shows pathloss distribution for a simulation having 120 MSs without the use of IR. It shows a bimodal distribution of pathloss which results from the urban simulation environment and pathloss models. Pathloss increases significantly at a corner as a result of diffraction of the signal, and this effect is modelled by the GRM, as previously described. Hence, this causes two modes of pathloss i.e., that due to links which include a corner, and that for which there is a simple LOS route.

Figure 4, shows the pathloss distribution in the same network, this time with IR implemented. Comparing it to Figure 3, it is clear that the two modes have moved closer together meaning that there are fewer links with pathloss in the highest regions. The clear separation of LOS and non-LOS links becomes less distinct with the introduction of IR. Consequently some of the higher loss links are eliminated and are moved into the intermediate pathloss range of 100-120dB, where previously (i.e., without IR) there were zero links.

Figure 5 shows the distribution of pathloss for a 120 MS simulation with and without IR, using a moving average to plot the trend lines from the data. The maximum pathloss is reduced significantly from 165dB to 150dB with the implementation of IR. Meanwhile, the peak frequency point of the first propagation mode at 85dB increases (although the moving average remains the same), while the peak of the second propagation mode is reduced from 145dB to 135dB.

It was therefore concluded that the minor savings of 0-4dB discussed in the previous section are in fact associated with low pathloss links, and that the higher savings can be associated with the links which have the largest pathloss. These results show that IR improves the pathloss most significantly for links which have pathlosses in excess of 145dB, hence improving link pathloss distribution.

These results have implications for both capacity and range of a system. The capacity of a system is dependant on the average power received by MSs and BSs, and thus, directly related to the average pathloss. The shift in distribution caused by IR would mean that more MSs could be supported on a network employing CDMA.

5. Practical and Commercial Discussion

This section of the report discusses the practical and commercial aspects of implementing IR in a mobile telecommunication network. Some of the many issues concerning the practical feasibility are discussed here, including the effect of IR on individual MS users and notable technological implementation details.

Intelligent Relaying on MS Users

IR will not be completely transparent to individual MS users. Relaying handsets will have a significantly higher power consumption compared to idle MSs in standby mode. The process of relaying requires processing energy, making it a power hungry operation. Individual MS users will have no reason to allow their phones to be used as relaying stations as battery life will suffer. It has been suggested that an incentives scheme could be introduced to encourage people to allow relaying through their phones. For example, a MS user could be given extra minutes for the time their phone is used as a relaying node.

A further problem that may impact MS users is that of availability. If a MS is relaying when a call is received, the line will either be engaged and unavailable, alternatively new handoff procedures will need to be introduced.

Technological Implementation Issues and Cost of Implementation

There are a number of technological challenges that will need to be addressed before IR can be implemented into a mobile network. These include issues of latency, hand-off, power control and routing.

IR adds latency to the system through the added processing required at each hop. Where the pathloss saving is insignificant, the increase in latency may outweigh the benefits of reduction in pathloss. Therefore, a future IR system would enforce a minimum pathloss savings value to ensure an overall improvement in service.

The issues of handoff and call blocking present another technological challenge. Handoff and blocking procedures will need to be developed for relaying MSs which receive calls, are switched off or move out of range while a relaying operation is in progress.

Routing is a major issue for IR with the determination of the best number of hops and relaying route being critical to system performance. In the simulations conducted in this project, the location of each MS in the entire system together with the urban environment parameters are known, permitting an ideal routing scenario. Such information may not be available in the real-world system and hence, a method of route discovery must be developed. Any search method will inevitably lead to a routing configuration which is less effective than the optimum routing employed in these simulations.

Under the Federal Communications Commission (FCC) Enhanced 911 requirements, a mobile network system must be able to locate a user to an accuracy of 125 metres 67% of the time. This presents challenges for IR systems as a MS connected through a relaying station would not be able to be located through conventional means of time of flight methods. One possible solution currently under investigation is the use of GPS in MSs.

Finally, the costs of implementing an IR system includes that of upgrading all existing handsets to comply with IR standards. Extra processing capabilities may be required in MSs. The cost of upgrading BSs or adding IR nodes will also include equipping them with new power control and routing protocols. The scale of these costs make a fully fledged IR implementation most suited to a future telecommunication system, rather than as an upgrade to existing networks. The use of fixed IR nodes could be a possible intermediate step to improve existing capacity and/or range in current networks without incurring large costs to individual MS users.

6. Conclusion

This report has shown that there are indeed quantifiable benefits of IR particularly in terms of the link pathloss distributions.

- IR improves the link pathloss distribution, with implications of both greater capacity and increased range for the mobile network system. Results showed that IR reduces the maximum pathloss by up to 15dB, while reducing the average pathloss by 10dB.

However, there are also notable practical and technical challenges that need to be addressed including a pathloss savings distribution with a high frequency of low pathloss saving links.

- Results of the link pathloss savings distributions show that IR has the highest frequency of savings in the 0 to 4dB range. Although these have been shown to be associated with low pathloss links, savings of such magnitude may not be significant enough to offset latency issues and implementation costs.
- The nature of relaying means that it is most effective when relaying nodes are in strategic positions such as at street corners. The mobility of MSs means that these benefits are rarely achieved or sustained. The use of fixed IR nodes could provide significant pathloss savings at lower implementation costs.

While it is not possible to make a conclusive decision based on the findings of this work alone, the results described here demonstrate the major characteristics and quantitative benefits of an IR enabled system. These provide a basis for assessing the feasibility of implementing IR in future mobile telecommunication networks.

7. References

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