Relaying in Wireless Access Networks

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A problem of limited resources

The telecommunications industry is currently faced with a tremendous task: an ever-increasing demand for mobile communication needs to be satisfied. Mobile communication can only be supported easily by using wireless, radio-based communication technologies. Radio communication exploits the capability of electromagnetic waves to convey information between senders and receivers. This process of information transmission is governed by fundamental laws of physics, given certain lower bounds on the amount of radio bandwidth that is required to achieve a desired speed of information exchange. Additionally, not all radio frequencies are easily amenable to information exchange, e.g., because some frequencies cannot penetrate walls.
These fundamental limitations result in an increasing demand for communication meeting only a fixed supply, and consequently, prices for this scare resource "radio bandwidth" are increasing - a phenomenon that has been demonstrated by the auctioning results for the UMTS frequency bands in Europe.
It is hence an important question how this limited resources can be exploited to its maximum possible extent: given a fixed amount of bandwidth, for a price has already been paid, are there mechanisms to increase the amount of communication that can be handled using it?

The attractiveness of relaying

Many different approaches have been considered to improve the capacity of a radio communication system, e.g., different modulation types, managing the access to the shared resource “radio channel”, etc. In this article, we like to discuss an alternative possibility to organize the exchange of information: relaying.

To formulate the problem more precisely, consider the following two basic scenarios:

- In the cellular network-type systems, akin to UMTS or wireless LANs like HiperLAN/2, a base station (or access point) controls a number of (mobile) terminals and all terminals directly communicate with this access point. The goal is to correctly transport as much data to and from the base station or access point as possible in a given amount of time.

- In a fully distributed ad hoc network (like 802.11 ad hoc mode) all terminals are equal, there is no base station which controls the communication, the terminals themselves have to organize the communication. In a system like this the goal is to ensure the full connectivity (if it is physically possible) between any two terminals. It is evident that the capability of relaying (an intermediate terminal transmits data from source to destination) becomes very important, since no one knows whether a source terminal’s radio can reach the destination directly or not.

We believe that the cell-based relaying systems will occupy a much more larger share of the market in the near future; hence we concentrate on this type of networks in the rest of this paper.

In a traditional cell-based system, all terminals communicate directly with their access point. In a cell-based relaying system, some terminals act as intermediate relays for other terminals, which only communicate with such relaying terminals, but no longer with the access point itself. Such relaying systems attempt to borrow some concepts of ad hoc networks in order to improve the operations of a traditional cellular network as illustrated by Figure 1.

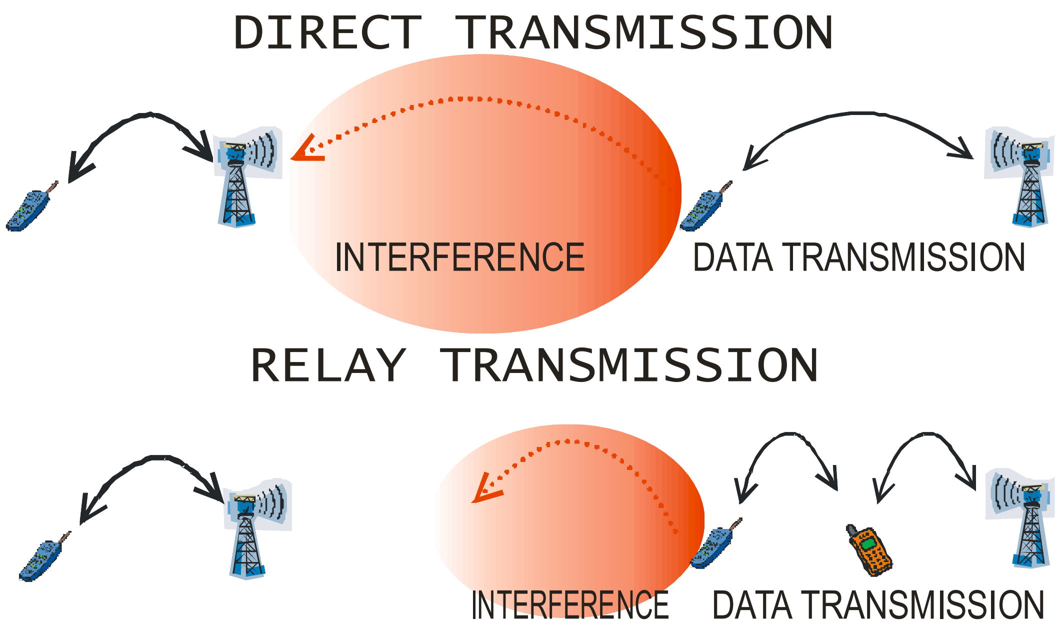

Figure 1

At a first glance, such a system does not appear to have any benefits over the traditional concept: data has to be transmitted twice; an intermediate system needs to be involved in the transmission of a given packet of data. Nevertheless, relaying could be beneficial with respect to three main points:

- Capacity. One of the main impediments to successful data transmission are errors caused by interference. As in a traditional network all terminals, even those far away from their access points, communicate directly with the access point, a high level of radiated power is required. This high power causes a lot of interference to the neighboring cells. Reducing transmission power would hence result in particular in a reduced inter-cell interference, resulting in smaller amounts of errors, effectively increasing the cell capacity. The reduction of radiated power is possible in a relaying system, as only smaller distances need to be overcome.
  The technical realization of capacity increase by relaying is complicated by the fact that the relaying terminals needs to transmit both its own data as well as the data coming from the other, far away terminals. In order to do so, it needs to transmit at a rate faster than used in a traditional, no-relaying system. But this is indeed possible as the reduced interference from other cells allows using faster modulation schemes.

Such a result can be exploited in two different ways: either as an improvement of the quality of a service a user sees, or as the potential to serve more users at the original quality of service without having to use more access points (alternatively, a fixed user population could potentially be served with fewer access points as well).

- Energy efficiency. The possibility to use lower radiated power when transmitting to a close relay station instead of to a far away access point also opens a possibility to improve the overall energy efficiency of such a wireless, cellular system. This possibility is due to the fact that in the power required to overcome a certain distance increases more than linearly with the distance: to cross twice the distance, four, eight, or even sixteen times the radiated power can be required (mostly depending on the type of the environment, indoor, outdoor, urban, etc.). E.g., transmitting over a 10m could be achieved either directly, using 102=100 units of power, or using a relaying terminal in the middle, using (10/2)2+(10/2)2=50 units of power. Evidently, considerable savings are possible, extending the time mobile terminals could work without having to be recharged.

  To do full justice to the energy efficiency problem, a full power budget of all communication devices must be considered. Therefore, not only the radiated power, but the total power consumed while transmitting or receiving needs to be considered. Power figures of today's technologies are such that relaying is attractive only in certain special circumstances (the main problem is the power offset caused by the amplifier). However, as the technology is projected to produce hardware that is inherently more power efficient, relaying could add some additional benefits (compare Figure 2).

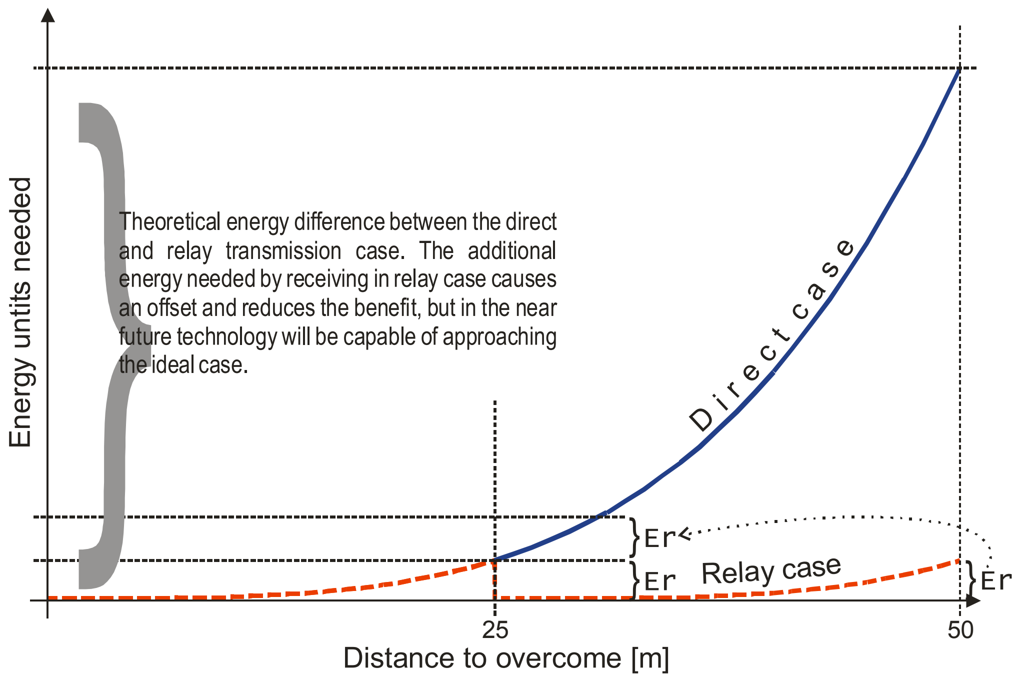

Figure 2

- Coverage. A third point is improved coverage. Evidently, relaying can be used to connect a mobile terminal to a base station that it would otherwise not be able to reach (due to limitations based on the maximum acceptable transmitted power). Extending the area of access points in such a way is actually one of the original applications of relaying in ad-hoc networks. The main benefit here is that, in order to provide radio-based connectivity to a given area, fewer access points would be required, resulting in a more economic way of providing the same level of service.

Keeping in mind Quality of Service requirements, some mixed solutions also have to be taken into consideration. An interesting idea is the usage of relaying stations only for transmitting data from the terminals to the base station. Since the base stations usually have infinite amount of energy, and are positioned near to the middle of the cell, they can transmit higher power in order to reach also the far terminals directly, while the interference to other cells is not increased. This solution reduces the possibility of errors during a transmission (which is of course corrected by the system in every cases, but reduces the overall system capacity), and also directly increases the capacity of the cell: The medium has to be used just three times instead of four (downlink traffic is only transmitted once).

However, it is not clear that the same level of service can actually be provided if the reach of an access point is extended by large amounts - this is still an area of active research.

Possible scenarios

All potential benefits of relaying are continent upon the willingness of participants to actually do relay traffic for other parties. Relaying can actually be a burden: energy is drawn from one's batteries, processing power and memory are used, etc. In order to identify reasons why someone should perform relaying duties, two broad groups of others can be distinguished: cooperating groups and groups of anonymous, mutually unknown participants.

Cooperating groups

In a cooperating group, there is an inherent desire or a purpose to communicate with other members of a group. Examples for such groups are groups of disaster relief troops, where only few entities can provide communication access to the outside world (serving as access points), work units in a construction site or an opencast pit, where the constant changing of the surface prohibits the installation of any kind of fixed radio equipment, or military units. In all these cases, the members of such group have to achieve a common purpose and hence a good reason to cooperate and to support each other. Another attractive scenario for relaying are exhibition halls or apartment blocks, where a lot of traffic needs to be conveyed in a small area. The reason here is that relaying, by virtue of reducing interference between entities, also them to be tighter packed, cells to be placed closer together, without causing too much disturbances. Hence, in an exhibition hall, more cells and more terminals can be installed compared to a traditional, directly communicating system.

Furthermore, the capabilities of the group members might be quite different: In the opencast mining example, all units might be in radio range of a central access point, but handheld radio devices typically only have a limited power supply, whereas the power supply of a truck or a caterpillar is not an issues. Hence, such heterogeneous systems can additionally benefit from replaying beyond the principle opportunities outlined above.

Anonymous relaying

Providing an incentive to cooperate as relaying entities is more difficult in a scenario where there is no inherent relationship between the parties involved. Typical cases here are the traditional, cellular telephony systems like GSM or UMTS. While a certain desire for altruism and technical nouvelle vague feeling has partially fueled systems like Metricom's Ricochet, it is somewhat unlikely that would be sufficient to convince normal users to provide relaying services. One possible incentive could be based on mutual benefit: only those users are allowed to use relaying service and to exploit its advantages which also provide this service to other users. However, the individual user is actually not the right level to look at for the highest benefit: the network as a whole gains larger advantages from relaying than an individual user. Hence, the network provider would be interested to see relaying take place (either because fewer access points might be needed or because more customers could be served with an existing set of access points or a better quality of service could be made feasible) and might therefore try to motivate its customers to participate in relaying. Possible mechanisms could include reduced costs or free transmission capacity.

Yet there are even anonymous groups where such relaying functionality could be beneficial: consider a car that has passed an obstacle on the road, say, a fallen rock. It could certainly be useful for all other cars to learn about this obstacle, and all car drivers would likely agree to pass on this piece of information to other cars, even though they do not have any initial relationship with other car drivers.

Open issues and current research

Some of the ideas and possibilities outlined above are already being put into products or are soon expected to be (e.g., the opencast mining example or the communicating cars examples). Nevertheless, a lot of open issues need to be solved. Foremost among them are security problems - tampering with data in the relaying terminal as well as denial-of-service attacks by request to be relayed or by denying relaying are but some potential problems that need to be solved - and actually detecting when relaying should be used and which terminal should relay for which other ones. Additionally, questions concerning the rate adaptation for the relay terminal (to enable it to handle both its own traffic as well as the relayed traffic) need to be solved. These last questions are the focus of our own current research, which concentrate on developing relaying solutions based on HiperLAN/2, with the goal of improving capacity and energy efficiency.

Conclusions

Relaying can be a solution to help with capacity, energy-efficiency and coverage problems in many wireless communication systems. While applications for cooperative scenarios are about to enter the market in the near future, additional research work remains to be done for anonymous groups, even though relaying likely holds the biggest promise is such environments.

Curriculum vitae

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Holger Karl obtained a Master degree in computer science from University of Karlsruhse in 1996 and a Ph.D. degree also in computer science from Humboldt-University of Berlin in 1999. He is currently working as a Wissenschaftlicher Assistant at the Telecommunication Networks Group at Technical University Berlin. His main research interests are ad-hoc networks, mainly focused on capacity and energy-efficiency issues and mobility support in IP-based networks, focusing on issues like Quality of Service and cross-layer interactions.

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Seble Mengesha received a B.Sc. and a M.Sc. in Electrical Engineering in 1995 and 1999, respectively, both from Addis Ababa University in Ethiopia. Currently, she is working at Technical University Berlin, Telecommunications Networks Group, in the context of the IBMS2 project. Her research work is focused on improving the capacity of single-relay cellular systems, using HiperLAN/2 as a case study.