Wireless World Research Forum
(WWRF)

Merging Cellular and Ad Hoc Networks by Relaying

P. Herhold, W. Rave, G. Fettweis

Dresden University of Technology
Vodafone Chair Mobile Communications Systems
D-01062 Dresden Germany
{herhold, fettweis}@ifn.et.tu-dresden.de

(b) Subject area: WG4

(c) Objectives for the required research

Undoubtedly, the capacity of both second and third generation cellular networks is limited by mutual interferences between transmitting network elements. Regardless of the access scheme, one user's transmitted signal ultimately represents interference for other users, and consequently degrades system performance. Minimizing radiated power is hence beneficial not only from the viewpoint of reduced electromagnetic emissions, but also from a capacity point of view.

Lowering the average transmitted power can be achieved by reducing the required quality of the received signal, or by reducing the propagation losses between the transmitting and receiving elements. While the former puts challenges on the physical layer design, the latter can be achieved by increasing the density of base stations in an infrastructure-based system.

Another approach to lower the overall propagation losses is to split the transmission path between remotely located terminals and access points into smaller segments by utilizing intermediate mobile stations as active reflectors. However, this increases the number of transmitting network elements and artificially increases emitted traffic, thereby counteracting against the intended reduction of overall transmission power.

A number of publications recently published reflects the augmented interest in this research area; a brief summary is given in the subsequent section. Yet, a deeper investigation is required to more profoundly understand the advantages and possible drawbacks associated with hopping in networks with a central control.

The main objectives of the proposed research items are hence

- To investigate the reduction of propagation losses achievable by relaying. That is, *to identify the potential power savings*.
- To study the feasibility of incorporating relaying methods into the various current and future cellular standards.

- To examine to which extend the reduction of total propagations losses can be turned into *transmission and interference power savings and hence capacity gains* for the systems and methods studied in the preceding point.
- To estimate the additional power consumed at the relaying stations.
- To understand how the additional spatial diversity introduced by the emission of identical information from multiple terminals can contribute to system-level performance.

(d) State of the art in the area

No intelligent relaying concept has been adopted in existing cellular systems so far. Solely bidirectional amplifiers have been used in 2G systems and will be introduced for 3G systems. Yet, these analog repeaters increase the noise level and suffer from the danger of instability due to their fixed gain. Both drawbacks have limited their application to specific scenarios.

Most existing and standardized systems were designed for *bidirectional* communication between a central base station and mobile stations directly linked to them. The additional communication relation between mobile terminals in relaying systems, however, calls for resources to be allocated to this relation - one of the facts that have prevented the introduction of smart relaying concepts so far.

TDMA-based systems are especially suited for relaying as the existing time division scheme allows for an easy allocation of resources to the mobile-to-mobile links. One possible approach is to use the timeslot allocated to a relaying station for the communication with the associated remote mobile terminals. This essentially requires subdividing this slot [1], which in turn causes a significant reduction of the system throughput [2]. Another method proposed for F/TDMA systems is to reuse a channel (frequency and time slot) from neighboring cells [3]. Other publications complement the research for relaying in TDMA networks.

The possibility of relaying in cellular CDMA-based systems is investigated by Zadeh et al. [4]. Uplink and downlink are separated using frequency division duplex, as it is done in IS-95 or UTRAN FDD. Due to this limitation of the number of available frequencies, operating the relaying links at a different carrier is not possible. Instead, a time division scheme is introduced, in which a relay station transmits and receives at the same carrier in an alternating manner.

With respect to relaying in the UTRAN, Opportunity Driven Multiple Access (ODMA) was believed to improve system coverage and possibly enhance capacity [5]. Yet, ODMA content was removed from the specifications in the March 2000.

A completely different approach is considered in [6] by incorporating an additional ad-hoc interface into the GSM protocol stack to enable relaying through this newly created interface. Similarly, Wu et al. [7] employ relaying stations to divert traffic from possibly congested areas of a cellular system to cells that exhibit a lower traffic load. These relaying stations utilise a different interface for communication among themselves and with mobile stations, which could for example be provided by a wireless LAN standard.

Besides expected improvements at system level, relaying has the capability of significantly enhancing spatial diversity as discussed in [8].

To summarize, relaying is broadly considered as a method to complement capacity and coverage in cellular systems. Despite the fact that currently introduced systems are CDMA-based, there has been a strong focus on relaying in TDMA systems. But as CDMA systems will take over the role which 2G systems play today, this calls for more active research on the relaying possibilities in cellular CDMA systems.

(e) Possible approach

With respect to CDMA systems, smart *ways of assigning the limited resources to the mobile-to-mobile links* need to be found such that the mutual interferences between the transmitting network elements are minimized. The constraint to be obeyed thereby is that a mobile acting as a relay will not be able to receive and transmit simultaneously at the same carrier. Similar to previous considerations [4], one approach might be to introduce an additional time division scheme for the relaying operation. Still, alternatives need to be considered since the introduction of such a scheme into an existing standard might cause unsolvable conflicts. Such an option could be provided by the existence of multiple FDD frequency pairs.

Most of the publications state that the protocol overhead associated with establishing and maintaining the relaying routes may become severe, thus possibly eliminating the use of true *multihop* techniques. Limiting the number of hops, i.e. eventually employing just a *single intermediate relay* station, is expected to greatly simplify the associated design challenges.

Having found the potentials for increasing capacity and reducing electromagnetic emissions, and having proved the basic feasibility, the next and final step is to focus on standardization issues.

(f) Expected results

The following results are expected

- Quantitative measures that describe the reduction of propagation losses of relaying systems with respect to conventional systems for typical scenarios.
- Quantitative analysis of the resulting transmit power reductions and coverage and capacity gains.
- Design principles and algorithms suited for introduction in 3G networks.
- Basic guidelines for standardization.

(g) Time frame to get the expected results

It is expected that the time frame for the research on relaying in cellular systems fits into the timeline presented in Fig. 2.3-1 of the Book of Visions.

List of references

[1] N. Esseling, H.S. Vandra, and B. Walke. A Forwarding Concept for Hiper-LAN/2. In Proc. European Wireless Conf., Dresden, Germany, September 2000

[2] Bernard Walke, Norbert Esseling, Joerg Habetha, Andreas Hettich, Arndt Kaldelka, Stefan Mangold, Joerg Peetz, Ulrich Vornefeld: IP over Wireless ATM – Guaranteed Wireless QoS with HiperLAN/2 (invited), Proc. IEEE, vol. 89, no. 1, pp. 20-41, Jan. 2001

[3] V. Sreng, H. Yanikomeroglu, and D. Falconer. Coverage Enhancement through Two-Hop Relaying in Cellular Radio Systems. In Proc. IEEE Wireless Commun. and Netw. Conf. (WCNC) 2002, vol. 2, pp. 881-885, March 2002.

[4] Ali Nabi Zadeh and Bijan Jabbari. Performance Analysis of Multihop Packet CDMA Cellular Networks. In Proc. IEEE Globecom 2001, vol. 5, pp. 2875-2879, San Antonio, Texas, November 2001.

[5] 3GPP. 3G TR 25.924 version 1.0.0, Opportunity Driven Multiple Access. Technical report, 3GPP, 1999.

[6] George Neonakis, Aggélou and Rahim Tafazolli. On the Relaying Capability of Next-Generation GSM Cellular Networks. IEEE Pers. Commun., 8(1):40-47, February 2001.

[7] Hongyi Wu, Chunming Qiao, Swades De, and Ozan Tonguz. Integrated Cellular and Ad Hoc Relaying Systems: iCAR. IEEE J. Select. Areas Commun., 19(10):2105-2215, October 2001

[8] J. N. Laneman, D. N. C. Tse, and G. W. Wornell. Cooperative Diversity in Wireless Networks: Efficient Protocols and Outage Behavior, January 2002. Submitted to IEEE Trans. Inform. Theory