Interconnection of Wireless Cells - a Multicast-based Approach

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Abstract

[1] [2] *This paper presents a solution to interconnect wireless cells to reach common LAN-dimensions. The protocol uses multicast to support fast handover in the presence of mobility in a local environment. The approach is strictly connectionless. A performance evaluation points out the benefits gained by using the multicast and estimates the drawbacks induced by the connectionless approach and by buffering.*

I. INTRODUCTION

The trend to increase the bitrates of wireless LANs will lead to very small radiocells, so called picocells. This trend follows clearly from the use of high radio frequencies (the higher the radio frequency the worse is the wall penetration), the tendency to limit the sending power (to preserve battery power and to avoid electromagnetic pollution) as well as tendency to spacial reuse of frequency. In addition a decrease of the number of mobile stations per radiocell is achieved, which improves the performance of the multiple access protocols. The coverage provided by such a small single picocell will definitely not be sufficient for a LAN if compared to commonly used LANs in terms of number of supported stations and coverage area. One can identify three different approaches to achieve the desired coverage: I. using network (or higher) layer functionality, II. forwarding of packets on the MAC layer, III. grouping of cells. In I. each radiocell forms a wireless LAN. The cells are interconnected by a internetwork protocol, e.g. Mobile IP requiring long distance mobility management. The forwarding approach in II. uses forwarders to transport packets over several wireless hops thus using more of the scarce wireless bandwidth and relying on the voluntary action of the forwarders. Wireless LANs based on the HIPERLAN-standard [1] use forwarding. This work focuses on the third approach chosen by the IEEE 802.11 [2] wireless LAN working group: the grouping of wireless cells over an infrastructure between the base stations to form a wireless LAN. [Figure 1]

A mobile source transmits a packet to a mobile destination in another cell within the LAN by sending it to the local base station. All basestations are interconnected by a LAN-technique with high bitrates and low error rates. The wireless LAN is connected to other networks by a Portal. The distribution system carries the packet to the right cell of the receiver. A mobile host must be able to move from one cell to another (handover) without decreasing the supported quality of the transmission. The IEEE 802.11 proposal specifies that the distribution system has to provide services for access, authentication, privacy, services for packet distribution and supporting services (association, re- and disassociation), but the draft does not standardize the distribution system any further, leaving its design implementation dependent.

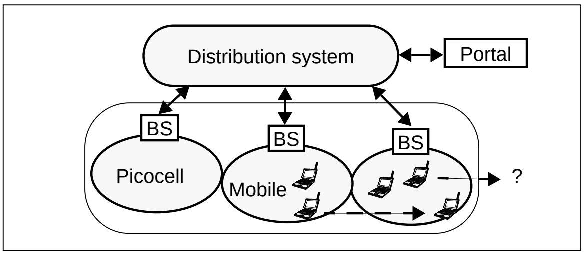

Fig. 1. Topology of a WLAN

Following a discussion of general issues we will present our design of the distribution system based on multicast. It is optimized for fast and efficient handover for time constraint multimedia data assuring a possibly continuous and relatively reliable service in spite of frequent handovers. We present a performance evaluation, discussing the benefits of the multicast scheme as well as the drawbacks by the connectionless approach and buffering.

II. GENERAL

The two main tasks of a distribution system are the packet transport between the basestations and mobility management, including locating a mobile station, interchange of location information and handover. Neighboring picocells operate in different channels, the channel is reused in a certain distance. The mobile stations of a picocell share a common channel by using a MAC-protocol. After a cell transition the mobile station cannot use the old channel any further and has to synchronize on the new channel, as soon as it is within range of the new basestation. The mobile station is provided with a single channel, so a handover 'in advance' is infeasible.

The protocol does not attempt to replace network layer functionality like MobileIP since it only offers local area mobility support [2]. If a cell transition between different WLANs took place, this case is given to higher layers. We refer mainly to the following work: In [3] a centralized network architecture with picocells

[1] This Work has been supported by a grant from the BMBF (German Ministry for Science and Technology) within the Priority Program ATM mobil.

managed by a supervisory host is proposed. A multicast protocol to support handover is applied. The supervisory host calculates trajectory prediction of a mobile station and forms a multicast group. All packets are multicast to this group. Our protocol differs from this work that we apply a strict connectionless multicast protocol in a distributed network architecture. We use hybrid scheme of registration, searching and self learning basestations for routefinding. Our multicast protocol is optimized for fast handover, but it requires toleraance of losses and packet duplication after handover.

III. The multicast protocol

The basic idea is, that packets are distributed across the distribution media by broadcasting them to all basestations. The basestations buffer the packets, the buffered packets are picked up by the mobile host at their current location. To avoid broadcasting to all basestations filling the buffers there, multicasting can be used to a selected group of basestations. The membership of this group can be dynamically formed. Before assigning a multicast group around the current location of a mobile station it has to be located. Therefore one can identify 3 distinct protocol functions, deduced by the tasks of the distribution system:

- locating the mobile station
- packet distribution
- handover support

Locating the mobile station

The protocol uses a hybrid variant of registration and searching. Every basestation manages a registration table. These tables remain local in the basestations and are not distributed. This saves the system from inconsistent information in different base stations and from high update traffic. Within the distribution system, a basestation has to search for the current location of the mobile by asking the other base stations. For registration purposes primitives are exchanged between basestation and mobile. The basestation makes an entry with timestamp into its table. The registration has to be updated by the mobile in certain time intervals. The timestamp is also updated by receiving a flag for an MAC layer acknowledgment. When a timestamp becomes outdated, the entry is deleted.

Packet distribution

A successfully registered mobile station transmits data packets to the basestation and waits for an MAC-layer acknowledgment before attempting further data transmission. At a missing acknowledgment the mobile tries to reregister. If the basestation receives a packet from its wireless MAC it checks its own cached search register for actual location information of the destination mobile. If no or an outdated entry exists, the basestation buffers the packets and searches the receiving host.

Handover support

If a mobile changes the picocell, it registers at the new basestation. Once a mobile host is reristered at the basestation it transmit all buffered packets to the mobile host. If the old basestation tries to transmit a packet it misses the MAC layer acknowledgment. It

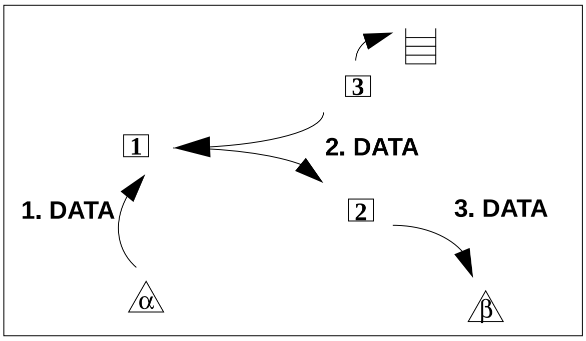

Fig. 2. Multicast with known receiver location

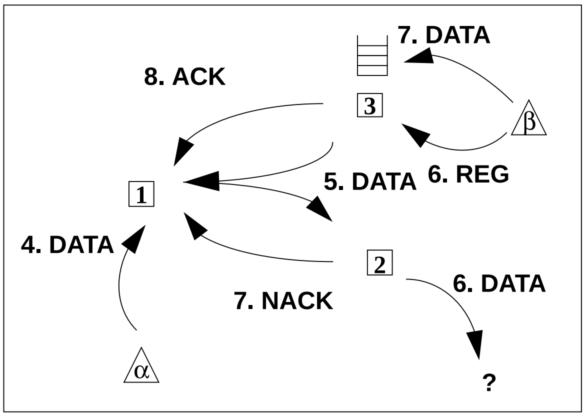

Fig. 3. Multicast after receiver cell transition

interprets this as a handover and informs the source basestation about the mobile's transition. The source basestation deletes the location entry of the basestation and initiate a new search, creates a new group of basestations and distributes the data packets to this new multicast group. If the data packet is part of a data stream, the mobile's location is tracked by sending a location information from the new basestation to the source basestation. This is triggered, when the new basestation empties its multicast buffer. The source basestation updates the mobile's location entry and do not need to initiate a new search.

Example

Suppose, the wireless LAN consists of 3 picocells, one fixed sender and one mobile receiver. We assume that the mobile stations have already registered at the corresponding basestations. DATA-packets are distributed from the sender α to the basestation 1, that forwards them to a multicast group [Figure 2]. Basestation 2, that is the current base station for receiver b transmits the packets on the wireless link, basestation 3 buffers them.

When the mobile station moves, it registers itself at the new basestation. The new basestation empties its buffer of already received packets and sends a location information to the source basestation. At the same time the new basestations sends an ACK-message for location tracking in the other base stations. The source basestation can now send immediately to the new multicast-group around the new location. [Figure 3]

IV. PERFORMANCE EVALUATION

Discussion of the methodology

The protocol achieves that packets are distributed between mobile stations, respectively buffered in basestations. This enables a fast handover but some drawbacks arise with it. The exchange of registration packets increase the load in the picocell. If searching of the receiving mobile host within the distribution system is necessary the packet delay grows. Subsequent packets however can benefit from the cached information. Packet duplication occurs due to the buffering of packets and the connectionless behavior of the protocol. The protocol however is designed to provide fast handover, as opposed to handover schemes aimed at reliability. For that reason, the packets are not provided with sequence numbers. Instead of sequence numbers a timer triggers the dropping of packets out of the buffer, if it becomes outdated. The value of this timer influences the loss or duplication of packets while handover take place. Assuming limited buffers we can loose packets due to buffer overflow and subsequent packet dropping following the simple buffer strategy that the oldest packet in the buffer is dropped first. The buffering of packets, especially since the buffers in the base station are shared by different mobile stations impacts packet loss and duplication. All mentioned factors have an effect on the overall performance of the multicast protocol. The criteria how to evaluate the performance of such a distribution system is an open question. Generally the handover performance can be quantified by comparing several criteria [4]:

- number of signalling messages exchanged during handover
- number of signalling messages exchanged during rerouting
- required buffer space
- duplication of data in distribution system
- duplication/misordering of data in mobile host
- duration of service disruption caused by handover.

We have chosen a pragmatic approach for performance evaluation. We simulate a dataflow between two mobile stations within two different picocells connected via a distribution system [Figure 4], and evaluate throughput and interpackettime over increasing load. For reference reasons we first estimate the quantities with fixed stations, this means that no handover occurs. This is compared to the dataflow with a moving receiver, initiating a handover in random time intervals. When the multicast is disabled, the loss can be evaluated. By using the multicast, the duration of service interruption is reduced and a gain expressed by throughput and interpackettime can be seen.

The simulation model and parameter

The simulations have been performed using the Ptolemy simulation tool [7]. The main parts of the simulation model are the protocol implementation of mobile and base-station, performing the mobility related tasks. Simplified modules are modeled for load generation, media access, physical layer, distribution system and simulation control. The load generation module generates packets with constant packet size at exponentially distributed times.

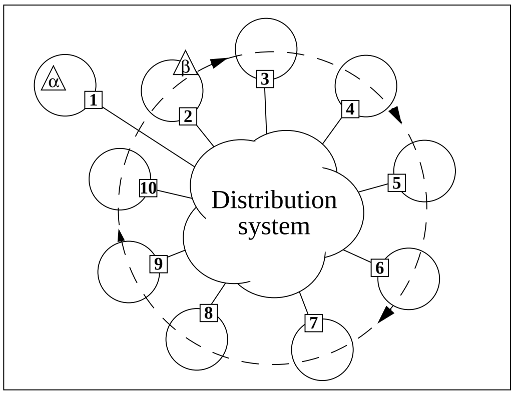

Fig. 4. The considered system

The media access and physical layer are modeled as single queues with deterministic service times, realizing media access time and packet delay. Background load can be simulated by varying the service time of the media access single-server queue. We fixed this service time to 0.5 ms. The model for medium access includes sending an immediate acknowledgement for each packet, so we got a maximum throughput of about 40% for the considered mobile station in relation to the overall throughput of the radiocell. We assume no packet losses on the physical layer to examine the packet loss due to handover.

We formed a network with 10 basestations. The distribution system provides a bitrate of 10 Mb/s per basestation (e.g. Switched Ethernet as a broadcast medium). The wireless link supports a maximum bitrate of 2 Mb/s, each 1 Mb/s on up- and downlink. Only 2 stations are present in the network, a virtual background load is modeled in the medium access. The case, that the mobile sender executes a handover is trivial, because it can be tracked by the basestation very easy. Therefore we considered only the case with a fixed transmitter and a mobile receiver. The mobile receiver executes frequent handover. Assuming an average moving speed of 1m/s and a radio cell diameter of 10m, a handover occurs in a random time interval after 10sec.

Simulation results

The main gain achieved by the multicast protocol is a reduction of the overall service interruption as illustrated in [Figure 5]. The fixed part of the interruption consists of the handover latency (HOL) (time for reaching the coverage area of the new base station, for synchronizing to the new channel) that cannot be influenced and the time for reregistration. After successful reregistration the already buffered packets at the new base stations can be transmitted - the flow of packets continues. Without the multicast scheme one has to wait for the expiration of the timer at the source base station. The source basestation then initiates a search. If the mobile host has already reregistered at its new basestation this search will be successful and data may again be sent. With the help of the multicast we can reduce the interruption for the time between the reregistration and the search.

The first simulation examines the throughput of the mobile station with increasing load [Figure 6]. The overall throughput without handover is 49% of maximum throughput at overload. The

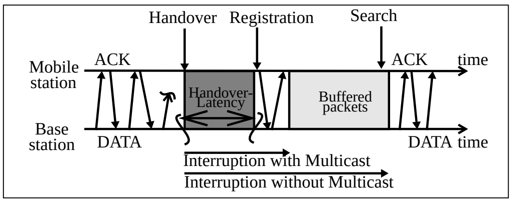

Fig. 5. Sending buffered packets after handover latency

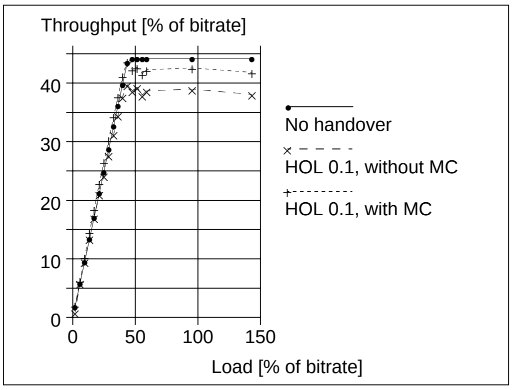

Fig. 6. Throughput of a mobile station at a handover latency HOL of 0.1s

handover induces a packet loss of approximately 5% of the maximum throughput at overload. Enabling the multicast the loss can be reduced to 2%.

We have varied the handover-latency from 0.1sec., 0.4sec., 0.7sec., 0.9sec. However we have only presented the results for a HOL of 0.1sec due to space constraints. The results show that the gain of multicast gets smaller with growing handover latency for two reasons:

- With growing handover latency the relation between handover latency and the time gap for transmitting buffered packets gets larger. So the gain of multicast gets smaller with growing handover latency.

- With growing handover latency, the number of dropped packets gets larger. This effect is intended! One of the task in protocol design is, that the handover appears transparent to higher layers. If the handover latency is very large (e.g. 1sec. - corresponding to a TCP-timer), higher layers should engage.

A throughput gain by multicast is visible under overload conditions only. Under normal load the packet loss during handover is compensated by a short-time increase of load. This load increase is limited by the buffer size for searching and the wireless link capacity. This effect can be described by evaluating the interpackettime at the receiving mobile host. [Figure 7] shows the mean interpackettime of a mobile station at a handover latency of 0.1sec. A minimum mean interpackettime can be reached at 0.1sec and will increase with growing handover latency, reaching a maximum at 0.9sec.

Note, that multicast influence under normal load can be observed rather in the interpackettime variance instead of in the

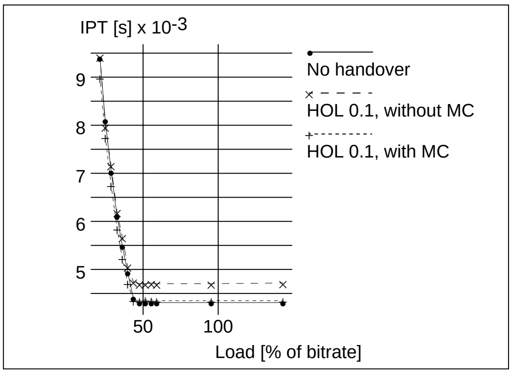

Fig. 7. Mean interpackettime of a mobile station at a handover latency HOL of 0.1s

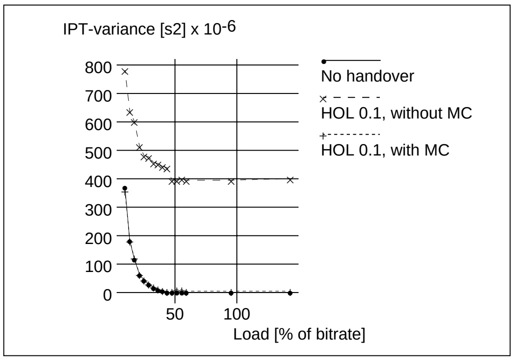

Fig. 8. Variance of interpackettime of a mobile station at a handover latency HOL of 0.1s

mean value. In [Figure 8] the curve for no handover and for mobile host with multicast supported handover are almost identical. The variance also increases with growing handover latency.

The above results have to be seen in perspective: The effective multicast throughput differs from the gross throughput. After a handover packets may be duplicated. The duplicated packets increase the throughput of the wireless link and have to be dropped at higher layers. At low handover latency the number of duplicated packets amounts up to 1.5% of the throughput, decreasing with growing handover latency. [Figure 9]

So far we assumed very large (nearly infinite) multicast buffer sizes. If we vary the buffer size, we expect a decrease of the multicast gain and probably a packet loss. When providing the basestations with very large buffers, a large amount of duplicated cells are transmitted over the wireless link. [Figure 10, 11] show this relation. For a handover latency of 0.4s the buffer size is increased (5, 10, 20, 50, 100, 500kbytes). It can be seen, that the effective throughput is already reached at 50kbytes. Beyond this point (e.g. 100 kbytes in [Figure 11]) only the transmission of duplicated packets increases. Note, that the buffer is exclusively assigned to a single mobile station. Sharing of buffer requires a buffer management with functions like flushing the buffer after handover, assigning buffer space to destinations with different bandwidth requirements etc. Further discussion deals with minimizing the needed multicast buffer size. One example (Delayed buffering) can be found in [3].

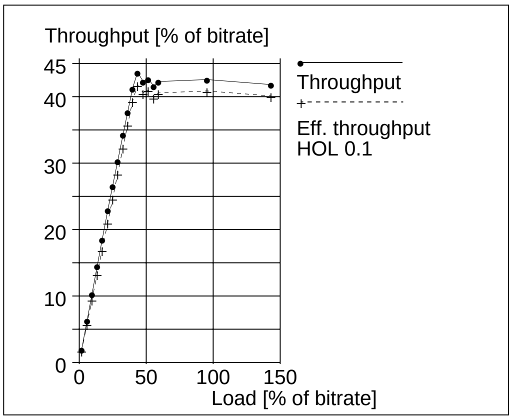

Fig. 9. Effective throughput of a mobile station at a handover latency HOL of 0.1s

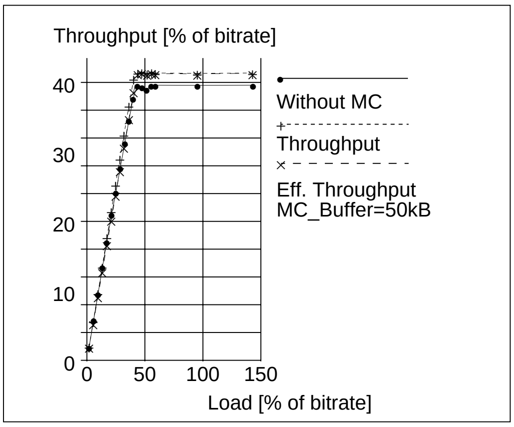

Fig. 10. Throughput of a mobile station with buffer size of 50 kbytes in basestation

V. Conclusions

A wireless LAN, similar to a IEEE 802.11 network, with 10 basestations, 1 fixed sending station and 1 receiving mobile station, with virtual background traffic on the wireless link is simulated. The mobile station executes frequent handover approximately every 10sec. We measured throughput and interpackettime dependent of handover latency and load. The simulation was realized for multicast supported handover and with disabled multicast in reference to fixed stations. Finally the multicast buffer size was varied. We examined normal load and overload conditions. The multicast protocol reduces the overall service interruption. It cannot change the handover latency, given as a physical constrain. The time between registration and rerouting is successfully used by sending the buffered packets. Under overload the overall throughput decrease of 5% under above conditions can be reduced up to 3.5%. Examining the effective throughput, including the drop of duplicated packets in the mobile station, leads to a approximately constant throughput decrease of about 2%. This gain can be watched under overload conditions only. Under normal load differences appear in the interpackettime variance only. Therefore we can say that the multicast scheme will provide a useful improvement for communication with very strict time constraints in a wireless LAN with very frequent handover events under medium to high load conditions.

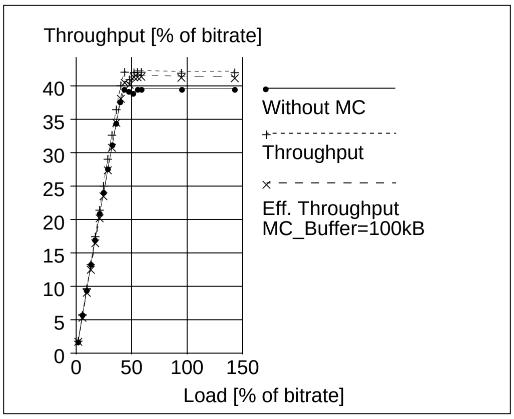

Fig. 11. Throughput of a mobile station with buffer size of 100 kbytes in basestation

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