Simulations on Heterogeneous Networking with CAHN

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***Abstract*— Nowadays heterogeneity of communication technologies would allow nodes to be optimally connected nearly anytime and anywhere. Unfortunately, the different technologies are not designed for seamless interworking. The heterogeneity is often perceived as a hurdle instead of an enabler for being *always best connected*. The dynamic selection and configuration of the most appropriate technology is by far too complex for the end user, especially when considering ad-hoc connections. The concept of *Cellular Assisted Heterogeneous Networking* (CAHN) provides a framework to offer convenient and secure management of heterogeneous end-to-end sessions between nodes. Furthermore, the proposed out-of-band signaling enables the seamless integration of ad-hoc links to offer best performance whenever nodes are within vicinity. The introduced separation of the signaling and the data plane allows to switch on power demanding broadband interfaces like GPRS, UMTS, or even WLAN only if actually required, i.e., data has to be sent or received). In this paper we present the potential benefits resulting from these two features enabled by CAHN. Extensive simulations show that both, the integration of ad-hoc links and the selective activation of high power broadband interfaces, can significantly increase the efficiency of heterogeneous sessions in terms of throughput and energy consumption.**

I. Introduction

The variety of access technologies becoming available forces the network operators to invest in heterogeneous infrastructure. Rather simple technologies like 802.11 (WLAN) outperform expensive well planned access networks like the 3G cellular network in specific conditions. These different access technologies have to be considered with respect to the environmental conditions and applications for which they have been designed. Some applications are preferably used in nomadic and some rather in a mobile way. To make the situation even more complex, there are applications that change their requirements depending on conditions like location, type of device used, or even type of session. This demand for heterogeneous access networks being able to deliver the right underlying technology to meet best the applications requirements at any time is also reflected by the efforts done in the research and standardization communities [1], [2]. The bundling of different access technologies in a seamless manner enabling handovers during ongoing sessions are further pushing the desire for being *always best connected*. Unlike these pure infrastructure-based solutions, which do not take into account infrastructureless communication, the integration of ad-hoc and peer-to-peer links can considerably improve the network performance in certain scenarios. Direct short range communication technologies like UWB achieve data rates beyond the boundaries of any infrastructure-based network. Integrating both infrastructure-based and direct communication links allows to switch automatically to the best suited technology. Whenever communicating nodes come close enough to use the high bandwidth direct links, they could benefit from the higher bandwidth and hence reduce the transmission time. Further information about how heterogeneity can improve the characteristics of communication sessions can be found in [3]. The next section briefly introduces the basic concept of cellular assisted heterogeneous networking. Section III addresses the problems of simulating heterogeneous networks with state of the art simulation tools and presents our own simulator. Simulation results are presented in section IV. Section V finally concludes the paper and gives an outlook to future work.

II. Cellular Assisted Heterogeneous Networking

To enable such an heterogenous networking enabling an *always best connected* experience throughout all available communication technologies including direct peer-to-peer links, an novel architecture and protocol was implemented and presented in [4]. The proposed system reuses the cellular network to bootstrap secure heterogeneous end-to-end sessions. The low power signaling channel of the cellular network is used to exchange configuration parameters and security credential among the participating nodes. Upon accepting an invitation for a heterogeneous session a node scans its environment for all available communication technologies and connects to the most appropriate one. The acquired IP address is then reported to the peer including further parameters like available bandwidth and security related information like used encryption mechanisms and keys. The system offers mechanisms to detect session peers if they are within the vicinity and prepares the direct peer-to-peer links for Mobile IP route optimization in terms of layer two and three connectivity. It enables therefore Mobile IP to perform a seamless handover between infrastructure and direct peer-to-peer mode. Ongoing sessions that are handed over to the direct peer-to-peer link are profiting from the higher data rates, which results in shorter session durations. Thus, depending on the bandwidth ratio between the infrastructure-based and the direct peer-to-peer link, the throughput can thus increase by orders of magnitude. When comparing state of the art GPRS and 802.11a ad-hoc mode or even UWB technologies, the throughput gain can highly influence the networking experience. Fig. 1 illustrates the session handover from infrastructure-based networks to ad-hoc links. First, node 1 is connected to the UMTS network and node 2 to the WLAN infrastructure (step 1). Due to the lower bandwidth offered by the UMTS connection, the session throughput is limited to the UMTS data rate. Is it therefore imaginable, that also node 2 switches to UMTS instead of using WLAN. However, such resource management decisions are not within the scope of this paper. If node 1 comes closer to node 2, it switches seamlessly to WLAN (step 2), which increases the session throughput to the WLAN data rate. As soon as the nodes detect each other to be within the vicinity they switch to the ad-hoc link (step 3).

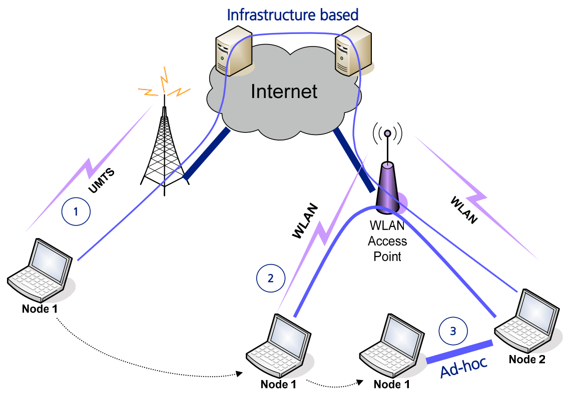

Fig. 1. Seamless Handover from infrastructure-based to ad-hoc links

The second key element of the cellular assisted heterogeneous networking (CAHN) concept is the ability to exchange signaling messages through any low bandwidth (and hence low power) channel like the cellular (e.g. SMS or USSD) prior to the actual broadband connection (e.g. GPRS or UMTS). Nodes can first send invitations for heterogenous sessions via the low power signaling channel (not necessarily IP based) and set up the expensive and resource demanding broadband data channels only upon acceptance. This ability to keep the broadband interfaces powered down until an actual data session is set up allows to save scarce battery energy. Hence, the introduction of CAHN enables a sort of *virtually always-on* experience, where a low power signaling channel guarantees reachability without requiring resource demanding IP connectivity. In the rest of this paper, this feature is referred to as *Broadband on Demand* (or simply on-demand).

In Fig. 2 the session bootstrapping like proposed in CAHN is illustrated. Node 1 invites node 2 to start an heterogeneous data session by sending a session request via the cellular network (step 1). Node 2 can either accept or reject the request by sending back a reply. In case of acceptance both nodes scan their environment for available communication technologies and connect to the most appropriate one (step 3). After exchanging the acquired IP addresses, they can set up a secured end-to-end session (e.g. VPN), which is represented with step 4. Using a low power cellular channel for the

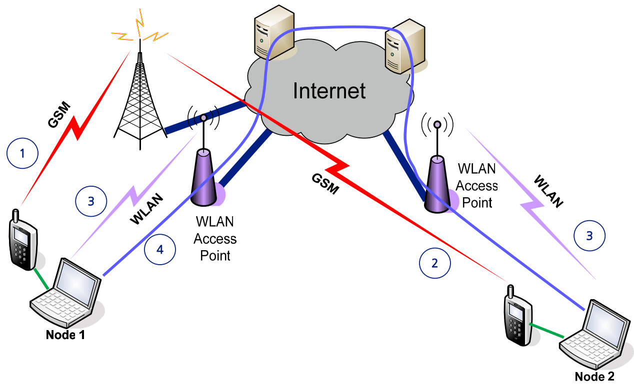

Fig. 2. Broadband on-demand enabled by CAHN

initialization of the broadband session, the nodes can be always reachable without keeping the energy demanding broadband interfaces in idle mode.

Both, the on-demand feature and the capability to seamlessly switch to direct peer-to-peer (or ad-hoc) links have the potential to substantially increase the performance of heterogeneous networking. To quantify this improvement potential simulations have been done based on a new simulator developed to meet the requirements of heterogeneous networks.

III. Simulation of Heterogeneous Networks

Existing network simulators (ns2, Qualnet, OpNet, etc.) do not provide appropriate support for the simulation of heterogeneous networks with dynamic vertical handovers during runtime, end-to-end communication between nodes using different wireless technologies simultaneously, and switching between infrastructure and ad-hoc mode of operation. Furthermore, these simulators either do not yet implement certain wireless technologies, e.g., GPRS in Qualnet, or implement different technologies for different incompatible versions, e.g., UMTS for ns-2.26 and GPRS for ns-2b7a. The necessary modifications to the network simulators to enable the simulations of the intended scenarios would require a tremendous implementation work and is out of scope of this paper. Therefore, we implemented our own network simulator that allows the modeling of heterogeneous networks at a simplified level. The simulator does not account for any physical propagation medium properties or MAC layer functionality and simulates sessions between peer mobile nodes at the application level, i.e., no packet transmission are simulated. The transmission ranges for different wireless technologies are modeled as circles with varying radiuses with respect to their characteristics, e.g., small radius for broadband technologies such as WLAN and UWB and larger radius for 2.5 and 3 G technologies with narrower bandwidth such as GPRS and UMTS. The amount of data transmitted is simply derived from the time attached to a certain technology and its bandwidth. Even though the simulator does not take into account the lower layers of the protocol stack, it allows the estimation of the possible benefits of the two main features of CAHN in heterogeneous networking environments, namely the ad-hoc and on-demand mode. The simulator implements the standard random waypoint mobility model and also the reference group point mobility model. In the former model nodes move independently of each other such that the period when two nodes are within transmission range and can communicate directly in ad-hoc mode is unrealistically short. On the other hand, the latter model allows the simulations of scenarios in which nodes move as a group such as on a train or a unit in a battlefield where the ad-hoc mode of CAHN is most beneficial.

IV. Simulations

In our simulations 50 nodes move over a given simulation area according to either the random waypoint (RWP) or the reference group point (RPGM) mobility model. An overview of this model can be found in [5]. Multiple random sessions are established between pairs of nodes where the session arrival rate is Poisson distributed and the amount of data to be transferred during a session is Pareto distributed. Each node always uses the available wireless technology with the highest bandwidth, i.e., a vertical handover occurs whenever a nodes moves into the range of a technology with a higher bandwidth. Consequently, the effective session transfer rate is the minimum bandwidth of the currently used technologies of the two communicating nodes. Three different wireless infrastructure-based technologies are deployed over the simulation area that differ in their bandwidth, range, and coverage to model existing or possible future technologies such as GPRS, UMTS, WLAN. Furthermore, there is an infrastructure-less wireless technology that allows for peer-to-peer communication such as WLAN or UWB. We devised four simulation scenarios by varying the node density, the number of sessions, the ratio of the bandwidth among the available wireless technologies, and the ratio of their coverage. If not noted otherwise, the other simulation parameters are kept fixed and set to the values as given in the following. The simulations last for 4600 seconds and sessions between nodes are only established after an initial warm-up phase of the mobility model of 1000 seconds to reach a stable state, i.e., traffic is generated during exactly one hour of simulation time. The simulation area is $3000\,m$ x $3000\,m$. In the random waypoint mobility model and the reference point group mobility model, nodes move with a speed between 1 and $15\,m/s$ and have a pause time of $30\,s$. The average group size is set to 4 with a standard deviation of 3 and a maximal distance to the group center of $50\,m$ in the group mobility model. Furthermore, nodes have a group change probability of 0.3. The session arrival rate is Poisson distributed with 4 sessions per hour and source-destination pair, which yields 100 sessions for 50 nodes. The amount of data is Pareto distributed between 10 KB and 100 MB. The bandwidth ratio for the three infrastructure-based technologies are set to 1 : 10 : 100 where the coverage is 100%, 50%, and 5% of the total simulation area, respectively. Considering today's deployed technology such as GPRS, UMTS, and WLAN, we believe that these values provide a reasonable rough approximation. The base stations are deployed randomly all over the simulation area. The number of base stations and the transmission radii for the respective technologies are varied accordingly to obtain these coverage values. Considering currently available technologies for node-to-node communication such as 802.11g or UWB, we can reasonably assume that node-to-node communication is 10 times faster than the fastest available infrastructure-based wireless technology. The transmission range for the ad-hoc technology was set to $150\,m$. We simulate these four scenarios for the four cases when nodes have each of the two features of CAHN enabled/disabled, i.e., neither ad-hoc nor on-demand mode enabled, have either ad-hoc or on-demand enabled, and have both modes enabled. We measured the average session duration and estimated the energy consumption to quantify the possible benefits of the ad-hoc and on-demand mode, respectively. All simulation results are given with a 95% confidence interval.

The values found in the literature for the energy consumption of the different devices are highly variable. The only consistent values were found for WLAN and thus, we tried best to estimate the average relative power consumption for the remaining types of devices, i.e. GPRS, UMTS [6], [7]. The values for WLAN have been also taken for the ad-hoc links.

A. Varying Node Density

In the first scenario, we evaluate the impact of the node density on the performance by varying the side length of the square of the simulation area from $1000\,m$ to $10000\,m$. For larger simulation areas, the probability that two peers can communicate directly in ad-hoc mode is smaller than when the nodes move in a smaller area and, thus, the benefit of the ad-hoc feature is reduced. This behavior is reflected in Fig. 3. Since the throughput is identical whether the on-demand feature is enabled or not, we did not consider the on-demand feature for the throughput evaluations.

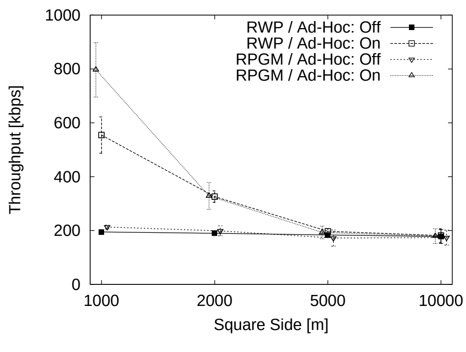

Fig. 3. Throughput for varying node density

For small areas the RPGM results in high probability that peering nodes come close enough to benefit from the high data rate ad-hoc link. For the smallest simulation area this results in average throughput increase from $200\,kbps$ up to $800\,kbps$. If the ad-hoc feature is disabled the throughput is quite constant for all simulation areas as the relative coverage for the different technologies is constant for all areas as expected. The average consumed energy per node for the different simulation areas is depicted in Fig. 4.

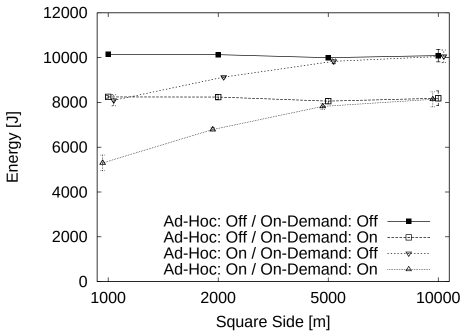

Fig. 4. Energy consumption for varying node density

In terms of energy consumption approximately 20% can be saved if the on-demand feature is enabled. Another 20% can be saved if the system can switch to ad-hoc links. This is mainly due to the increased throughput, which in turn results in shorter session durations. (For the energy consumption evaluation, the RPGM and the RWP were not differing that much and therefore the results for the RPGM are not shown for sake of clarity and lack of space.)

B. Varying Session Density

If the session density is very high the nodes are constantly transmitting and/or receiving data anyway such that the on-demand feature of CAHN is not really beneficial. However when nodes receive data only very infrequently, CAHN enables nodes to be in sleep mode and be nevertheless reachable for session invitations. Unlike for CAHN-enabled nodes, "normal" nodes have to remain in idle mode to be reachable for incoming data all the time. In today's devices however, the energy consumption in idle mode is significantly higher than in sleep mode. This allows CAHN-enabled nodes to reduce significantly the use of scarce battery power. In these simulations, we varied the amount of transmitted data by the session arrival rate which is Poisson distributed with 1 and 40 session per hour and source destination pair. In Fig. 5, the impact of the session density on the average throughput of the sessions is depicted.

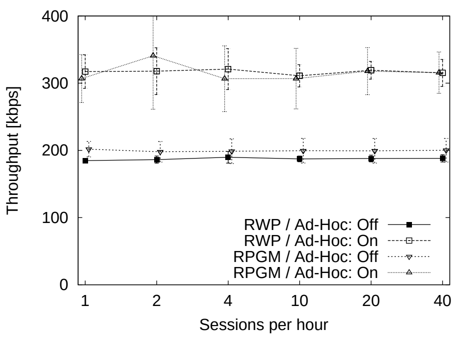

Fig. 5. Throughput for varying session density

Since here the simulation area was set to $2000\,m$ x $2000\,m$, the improvement is consistent with the one depicted in Fig. 3. The difference between the RPGM and the RWP mobility model is not as big as expected, which is due to the small group size chosen for the RPGM. With bigger group sizes the probability that two communicating nodes are within the same group and hence able to use ad-hoc links is significantly higher. However, choosing the group size too big is not realistic neither.

Fig. 6 shows the energy consumption values for the different numbers of sessions. The potential energy savings strongly depend on the number of sessions, since the devices are only switched to sleep mode if no session are ongoing. Again, the increased average throughput with enabled ad-hoc mode is shortening the average session duration and thus the energy consumption.

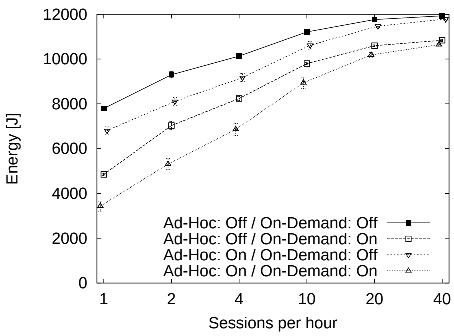

Fig. 6. Energy consumption for varying session density

C. Varying Bandwidth Ratio

We basically distinguish between four kinds of wireless technologies in this paper, three infrastructure-based and an infrastructureless technology for peer-to-peer links. The first kind of technology provides almost full coverage but has only limited bandwidth such as GPRS, EDGE, or also satellite networks. The second kind of technology constitutes 3G wireless networks such as UMTS, HSDPA, which provide higher bandwidth, but are not yet as widely deployed as 2 and 2.5G networks, perhaps only within urban areas. Wireless broadband technologies are the third kind of infrastructure-based technology considered in this paper, which are commonly not area-wide deployed, but at specific locations only, such as 802.11b in so-called Hotspots. Fourth, nodes can communicate directly without any infrastructure in ad-hoc mode with certain technologies such as WLAN or UWB. Depending on the technologies in use, the current active users, the signal-to-noise ratio, and/or operator policies, etc. the ratio between these technologies may vary strongly. We evaluated two scenarios and set the bandwidth ratio of the technologies with respect to the first technology (e.g. GPRS) providing the highest coverage. In the first scenario the second technology (e.g. UMTS) provides 2, the third (e.g. WLAN) 20 and the ad-hoc (e.g. UWB) 1000 times more bandwidth than the first technology. The second scenario was simulated with a technology bandwidth ratio of $1 : 10 : 100 : 1000$. Fig. 7 shows the variation of the average throughput if the bandwidth ration of the different technologies is changed. The first scenario, having a very high discrepancy between the data rates offered by the infrastructure-based and the ad-hoc communication technology, is very much profiting from the ad-hoc feature, whereas the throughput increase in the second scenario is only about 20%.

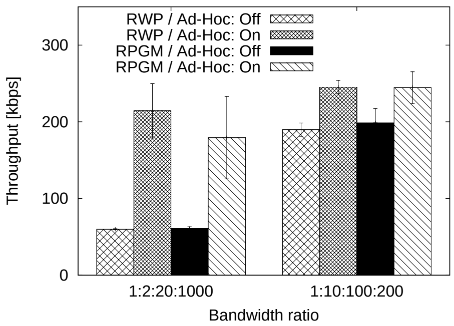

Fig. 7. Throughput for varying bandwidth ratio

Assuming further development of high bandwidth ad-hoc technologies like UWB offering data rates that are by orders of magnitude higher than the ones available at infrastructure-based networks, the capability of seamlessly switching to ad-hoc links becomes crucial to improve the average throughput. In our simulations the average throughput can be increased up to a factor of 4.

D. *Varying Coverage of Infrastructure Technologies*

In this last scenario, we analyze the impact of the coverage of the three different infrastructure-based technologies on the performance. We consider two specific cases where the coverage of each technology is very low and very high, respectively. In the first case, the coverage of the first, second, and third technology is $50\%, 25\%$, and 1% whereas in the second case the coverage was $100\%, 80\%$, and 10% of the whole simulation area, respectively. The impact of the variation of the relative coverage is depicted in Fig. 8.

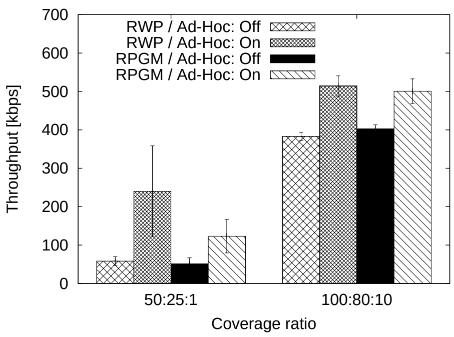

Fig. 8. Throughput for varying coverage

For low coverage of infrastructure-based technologies the gain of the usage of the ad-hoc link is higher than for well covered areas. In the first scenario with low coverage the probability of having no or only very narrow band connection is rather high. Thus, even if the chance of having direct communication via the ad-hoc links is small as well, the impact on the session throughput in case of occurrence is very high. When focusing on the energy saving potential the ad-hoc feature is not as advantageous as the on-demand capability as observed in Fig. 9.

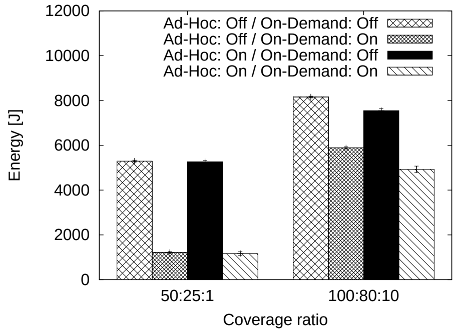

Fig. 9. Energy consumption for varying coverage

V. Conclusion And Outlook

The first part of the paper discussed briefly the CAHN framework and the problem of simulating heterogeneous networks with existing state of the art simulators. After having presented the four test cases the simulation results were evaluated in terms of throughput gain and reduction of energy consumption. We have seen that the throughput can be increased by up to a factor of 4 and the energy consumption reduced about 80% in certain scenarios. The two features offered by the CAHN framework, namely the *ad-hoc* and the *on-demand* capability are promising increased networking experience not only for the user, but also for the operator, in terms of better battery lifetime and more efficient resource utilization. For future work, we plan to extend the simulation tool by more realistic movement patterns and to handle base stations and access point with limited capacity to obtain more realistically simulation results.

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