Multicast Bearer Selection in Heterogeneous Wireless Networks

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***Abstract*— Network scenarios beyond 3G assume the co-operation of operators with wireless access networks of different technologies in order to improve scalability and provide enhanced services to their mobile customers. While the selection of an optimised delivery path in such scenarios with multiple access networks is already a challenging task for unicast delivery, the problem becomes more severe for multicast services, where a potentially large group of heterogeneous receivers has to be served simultaneously via shared resources.**

In this paper we study the problem of selecting the optimal bearer paths for multicast services with groups of heterogeneous receivers in wireless networks with overlapping coverage. We propose an algorithm for bearer selection with different optimisation goals, demonstrating the existing tradeoff between user preference and resource efficiency.

I. INTRODUCTION

In the recent years the demand for ubiquitous wireless data services rose dramatically, as the Internet becomes more and more popular and end users increasingly mobile. Services such as push delivery of content, video and audio streaming, multimedia conferencing and multiplayer games are expected to become a major source of revenue for both network operators and service providers. In order to overcome scalability problems, multicast transmission has been proposed as resource efficient delivery mechanism on the Internet [1]. Recent standardisation efforts such as Multimedia Broadcast and Multicast Services (MBMS) [2], [3] aim to support this mechanism in 3G cellular networks. Resource savings are achieved by constructing a shared delivery path for a group of users throughout the core network and by utilising shared channels over the radio link, where and whenever appropriate.

In a beyond 3G network scenario operators with wireless access networks of different technologies, such as mobile (e.g. UMTS) and broadcast (e.g. DVB-T/H), are expected to cooperate [4] in order to improve scalability and provide enhanced services to their mobile customers. Thus mobile users will be able to receive data services from various access networks available at their location; possibly using multimode devices or multiple access devices that are part of their personal area network (PAN). While the selection of an optimum delivery path for a unicast service for a single receiver may be already a challenging task, the problem is more severe for multicast services, where a potentially large group of heterogeneous receivers have to be served simultaneously via shared resources. Receivers may be geographically wide, having different network access devices (NADs) [1] with different capabilities and delivery preferences. Trying to satisfy the individual users' choice in a delivery network often leads to the situation that the same content may be delivered via several access networks to the same location. Thus there is a tradeoff between satisfying user preference and resource efficiency. Furthermore, due to the unavailability of network resources, an access network may become temporarily unusable for the service delivery. The choice for an alternative bearer path may not satisfy all receivers at a location, due to the unavailability of an appropriate NAD. Additionally, service characteristics such as the size of or the locality of service content may make some access networks more suitable than others. Consequently the selection of the optimum delivery paths to satisfy all receivers of a multicast service is no straight forward task.

In this paper we study the problem of selecting the optimum bearer paths for multicast services with a group of heterogeneous receivers in wireless networks with overlapping coverage. We propose a bearer selection algorithm, suitable for different optimisation goals and undertake performance evaluations assuming overlapping UMTS and DVB networks. We concentrate on two optimisation goals, namely resource utilisation and user access device preference.

The remainder of the paper is structured as follows: section II briefly reviews the existing background and related work. Section III presents the proposed multicast bearer selection algorithm, explaining the operations for the different optimisation goals. In section IV we present simulation results and analyse the performance of the proposed algorithms. We give some final remarks in V and conclude the paper with an outlook on our ongoing work.

II. BACKGROUND AND RELATED WORK

With the introduction of MBMS in UMTS Release 6, multicast data delivery becomes possible in cellular networks, allowing a potentially large set of receivers to be served efficiently by a single multicast transmission. This is achieved by constructing a shared delivery path in the core network and

[1]The concept of a NAD actually refers to a network access interface of a terminal. Thus a user may have a physical terminal with several NADs, interfacing to different access networks or may have different physical terminals each for a distinct access network.

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by utilising shared radio bearers over the last hop wireless link. Within the MBMS standardisation process, work has been done on the selection of point-to-point (p2p) and point-to-multipoint (p2mp) radio bearers. The challenges lie in selecting the appropriate radio bearer depending on the number of users in a cell, since few p2p bearers can outperform one p2mp bearer in terms of resource efficiency [5]. This is possible, since unlike the p2p bearers, p2mp bearers lack power control. Our work, in contrast, considers the selection of multicast bearers across multiple access network with overlapping coverage. Receivers are heterogeneous unlike in a network scenario with a single access system, since different network access devices with different capabilities may be available at each individual receiver.

Several European [6], [7], [8], [9] and international projects [10] have already studied the integration of different wireless access technologies to provide better coverage and enhanced provision of data services to mobile users in a beyond 3G scenario. Particularly [11] and [6] have considered multicast delivery in more detail. [6] proposes a delivery subsystem and support platform for IP data delivery in DVB and UMTS networks. The selection of a multicast bearer on an access network, however is purely based on receiver decisions. In [11] the different access systems, e.g, UMTS, DVB and WLAN are interconnected by a common core network with enhanced functionality. The essential part for multicast service provisioning is a group management function, which is aware of all receivers within the multicast group and has access to current resource information of the networks and capabilities of the receiver devices. The group management function is used to optimise multicast transmission to mobile receivers over the available access networks [12]. Although, a lot of conceptual work has been contributed, it lacks of actual mechanisms or algorithms to achieve the optimised delivery. In contrast our work rather explores a practical approach to achieve these optimisations for multicast delivery.

III. Bearer Selection Algorithm

We assume that a set of receivers has expressed their interest in receiving multicast content by a previous subscription to a group management service in the network, similar to MBMS [3]. Furthermore, at the start time of the service, the group management service is able to access user related context information such as location, access devices and device preferences for the subscribed service. This information can be obtained from one or various network databases, which are continuously maintained for every receiver, or it can be partly provided by the receivers during the subscription process. Furthermore, it is assumed that current resource information is known for every cell of the cooperating networks. The information can also be obtained from distributed resource managers as described in [13].

Using this information a bearer selection algorithm is able to determine a set of suitable bearer paths across multiple cooperating access networks. The way an algorithm selects these bearer paths depends on its optimisation goal.

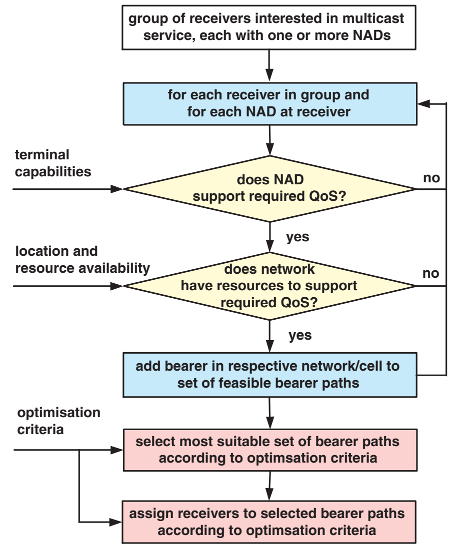

Fig. 1. Basic procedure for bearer selection. First the set of feasible bearer paths is identified for receivers in a multicast group. Then the most suitable set of bearer paths is selected according to optimisation policies.

We first present the general structure of bearer selection algorithm and then present a heuristic solution.

A. Basic Principles

In the following we describe the main principles of the multicast bearer selection. Initially the set of all feasible bearer paths to the group of receivers over the various available access networks are identified. Then, out of the determined set, a suitable combination of bearers is selected and receivers are assigned to the selected bearers according to an optimisation policy.

The identification of all feasible bearer path is achieved by a two step procedure. In a first step for each network the cells are determined, which have receivers present with a NAD supporting the required QoS for the service. Then, as a second step, resource management of the respective networks is queried to identify those cells, where a multicast bearer with the required QoS could actually be established. Figure 1 shows a flow diagram of a possible implementation of the initial stage and the required context information at each of the steps. The result of the stage is the set of feasible multicast bearers to serve at least a subset of receivers interested in the multicast service. Once the set of feasible bearer paths is determined, a suitable combination of multicast bearers needs to be selected. Furthermore the receivers need to be assigned appropriately to the selected bearers. The way how the selection is performed and how the assignment of receivers to bearers takes place is subject to the optimisation policy.

We now present a heuristic solution for the selection and assignment operation. The approach can be summarised in the following three steps and is further explained in the remaining subsections:

1) Partitioning of the receivers into a *hard set*, *excluded set* and *flexible set*

2) Selection of bearers required for the receivers in the *hard set* and assignment of receivers to selected bearers
3) Selection of additional bearers, if required for the receivers in the *flexible set*, according to an optimisation policy, and the appropriate assignment of those receivers to selected bearers.

B. Partitioning Rules

The partitioning of receivers is a preprocessing stage of the bearer selection process. It helps to identify, which bearer paths are essential, optional or impossible to be established. The following rules apply for the partitioning:

The *hard set* is formed by receivers for which only one bearer path exists. Thus a multicast bearer can be established only for a single NAD at the receiver. This may have different reasons: either there is only a single NAD available at the receiver, or maybe some NADs may not support the required QoS of the multicast service. Other reasons may be the lack of coverage for a particular access network at receiver location, or insufficient network resources for the establishment of a multicast bearer with a required minimum QoS.

The *excluded set* represents the set of receivers for which no bearer can be established. Hence receivers in the excluded set are blocked in case of service provision.

Finally the *flexible set* includes all receivers for which more than one bearer path can be established. Thus receivers in this set have multiple NADs available for which an alternative multicast bearer with the required QoS can be established at their current locations. Receivers in this set represent the main group on which optimisation can be performed.

C. Hard Set Selection and Excluded Set

Since no alternative delivery path exists for receivers of the hard set, the establishment of respective multicast bearers is essential for their support. Thus the algorithm selects the required multicast bearers and assigns the receivers accordingly to their available NAD.

The receivers in the excluded set remain unsupported for the multicast session, since appropriate multicast bearers cannot be established. It is up to the service provider to decide how to handle receivers in the excluded set. Instead of simply blocking the receivers, one option would be to re-schedule the receivers for the next session of the same multicast service. This may be suitable for multimedia on-demand services with batching possibilities, however may not be appropriate for services such as real-time multimedia streaming of live events. Alternatively some receivers of the excluded set may be served by unicast bearers [2] if the NADs and resources in the respective networks allow the establishment of respective point-to-point bearers.

D. Flexible Set Selection

Service delivery to receivers in the flexible set can occur via two or more delivery paths. Thus optimisation can be achieved by carefully selecting when necessary additional delivery paths and assigning the receivers of the *flexible set* to the selected bearers according to some optimisation rules. As previously mentioned we focus on two optimisation goals namely resource efficiency and receiver preference. We propose three simple selection and assignment mechanisms, which differ in their optimisation goal for the flexible set.

1) MaxPref Selection: The *MaxPref* selection represents the purely receiver-driven selection approach, as common in current multicast on the Internet. For each receiver the preferred NAD is selected. If the respective multicast bearer for that NAD has been already selected by the hard set selection at the receiver location, then the receiver becomes assigned to the selected multicast bearer. Otherwise the multicast bearer is added to the selected set and the receiver is assigned accordingly.

2) MinLoad Selection: MinLoad optimisation tries to avoid a selection of a new multicast bearer whenever possible. It therefore first checks if the receiver has a NAD which has been already selected for receivers in the hard set. The following three cases can occur:

- Only one multicast bearer has been already selected for the available NADs at the receiver. The receiver is assigned to the multicast bearer.
- More than one multicast bearer has already been selected, which suits available NADs. The receiver is assigned to the multicast bearer in the currently least loaded cell.
- None of the bearers has been preselected. The selection decision is postponed until all remaining receivers have been identified for this case. Then a joint decision for these receivers is made considering the selection of bearers which causes the least overall load to the system.

3) MinLoadPref Selection: MinLoadPref optimisation tries to avoid the selection of a new multicast bearer, however whenever possible assigns receivers to multicast bearers of preferred NADs. Compared to the *MinLoad* optimisation, the algorithm differs slightly in the last two cases. The following three cases are possible for every receiver in the flexible set:

- Only one multicast bearer has been preselected for all available NAD. The receiver is thus assigned to the multicast bearer.
- More than one multicast bearer has been preselected, which suits available NADs. The receiver is assigned to the multicast bearer according the most preferred NAD.
- None of the bearers has yet been selected. A multicast bearer is selected for the most frequently preferred NAD. The receiver is then assigned to the respective bearer.

IV. Performance Evaluations

In this section we evaluate the proposed bearer selection algorithm by simulations. The algorithm was implemented for the three optimisation objectives, which are analysed and compared in the following subsections. All simulations were performed using the discrete event simulation environment OPNET 10.

[2] As aforementioned, in UMTS p2mp bearers are less resource efficient than p2p bearers because of the lack of power control.

TABLE I
NETWORK SCENARIO.

Network	Cells	Available Bandwidth	Preference Ratio
UMTS	7	512k	50%
DVB	1	1024k	50%

TABLE II
RECEIVER HETEROGENEITY ASSUMPTION.

Receiver NADs	Case I	Case II	Case III
UMTS only	50%	25%	0%
DVB only	50%	25%	0%
Both	0%	50%	100%

A. Simulation Scenario and Performance Measures

For simplicity of the study we consider a scenario with only two wireless networks, namely UMTS and DVB-T/H. The algorithm however is also applicable to scenarios with multiple overlapping access networks. Table I briefly summarises relevant network parameters. In our scenario 7 UMTS cells are covered by one DVB cell. Within the area covered by the cells 1000 receivers are uniformly distributed. Furthermore, we model the heterogeneity of receivers in terms of availability of access devices and preference for a certain device to receive a service. Thus, two basic classes of receivers are defined: receivers that are able to receive only one of both networks and receivers that are able to receive from both of the networks. The latter have a preference order associated for each NAD. For our simulation we assume 50% prefer the UMTS NAD and 50% the DVB NAD. Receiver heterogeneity is evaluated for three different cases as summarised in table II.

For various service arrival rates and different service popularity we evaluate the selection schemes using the following performance measures: average network load, average user blocking, service blocking and satisfied user preference.

At the time of each service arrival a subset of receivers is selected to be interested in that service. The number of receivers for a service as well as which receivers are interested in a service are determined by uniform distributions. We classify services into three types according to their popularity: for services with low popularity we select 1-4% of the receivers, for services with medium popularity 4-7% and for services with higher popularity 7-10%. Table III summarises relevant service parameters. We assume the services to be typical multimedia streaming services with a duration of 5 min and an average required bandwidth of 128 kBits/sec.

Depending on the service requirements, necessary resources are allocated in the respective cells of the receivers to serve the group for the service duration. If, for a particular bearer selection, resources in one or more cells are insufficient to satisfy the service requirements, then bearers cannot be established in those cells. Receivers requesting or being allocated to these bearers are thus blocked for the service. The service is still provided to the remaining receivers, and the respective resources remain allocated until the service terminates. A service is only blocked if no bearer at all can be established due to lack of resources, thus all receivers are blocked for the service.

TABLE III
SERVICE PARAMTERS.

Service Load	0.5 - 6 services/min
Duration	5 min
Bandwidth Requirements	128k
Receiver Interest	1-4%, 4-7%, 7-10%

For all supported receivers with both access devices the preference satisfaction ratio is determined, according to the selected bearers in the following way: A ”1” is counted for each receiver if the preferred device for the service delivery has been selected - otherwise ”0”. The preference satisfaction ratio of a service is then the sum of the preference values averaged with the number of those receivers.

B. Discussion of Simulation Results

Simulation have been performed for each of the optimisation approaches. Each run was stopped at about 10,000 requested services. Thus the duration for each run varied for different traffic loads. Although most of the results converged much earlier, the value was chosen to guarantee a good significance with regard to the service blocking rate. Figure 2 shows the average service blocking rate for the receiver heterogeneity case II, considering the three different optimisation approaches for different levels of receiver interest. As expected the service blocking increases with higher service load. The *MaxPref* approach has the highest blocking rate. *MinLoad* as well *MinLoadPref* perform equally good and as expected better than *MaxPref*. Both approaches allow up to a 50% service load at the same service blocking rate e.g. for at a rate of 0.25, 3 service/min can be offered instead of 2 for low interest services.

Figure 3 shows the the average user blocking probability per service. Analogous to the service probability *MinLoad* and *MinLoadPref* achieve the same user blocking as *MaxPref* at higher service load. The improvements of the user blocking rate are still around 30%.

As previously mentioned, the *MaxPref* approach represents the current receiver-driven IP multicast approach, where users individually decide from which access network to receive a multicast session. In contrast *MinLoad* and *MinLoadPref*, allow much higher service load and offer lower user blocking, as compared to the *MaxPref* approach. Thus it can be clearly seen that a selection of multicast bearers, which is coordinated over multiple access networks, can significantly improve the overall resources efficiency for the provision of multicast service.

The tradeoff between resource efficiency and user preference satisfaction can be clearly seen when comparing the

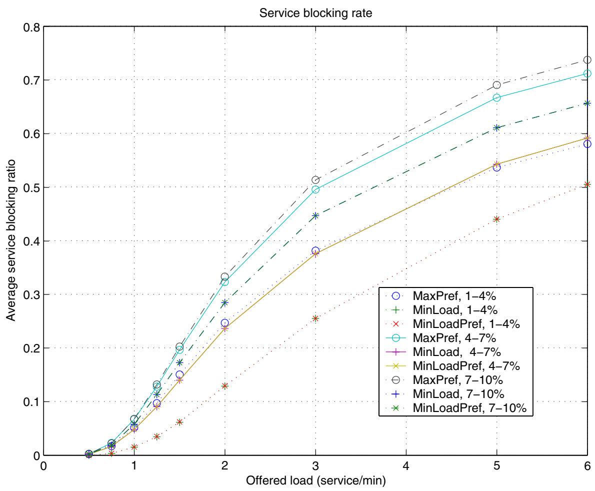

Fig. 2. Service blocking ratio for heterogeneity case II.

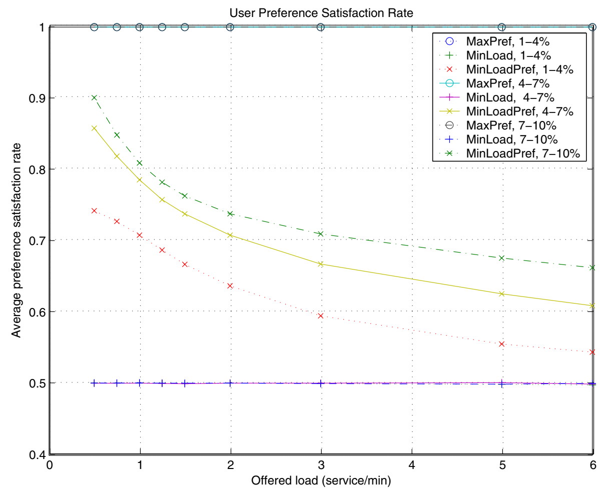

Fig. 4. User Preference Rate for heterogeneity case II.

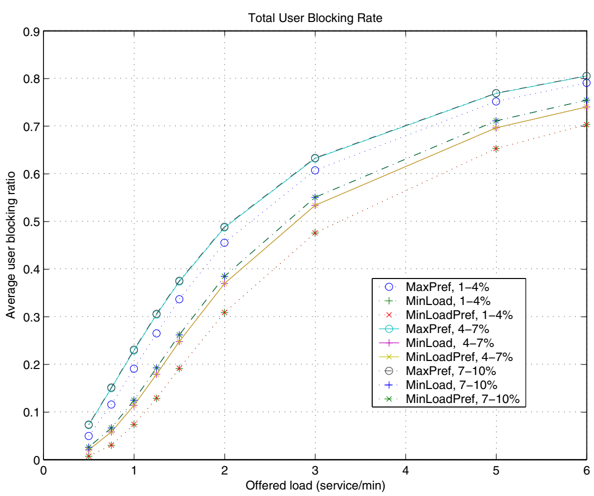

Fig. 3. User blocking ratio for heterogeneity case II.

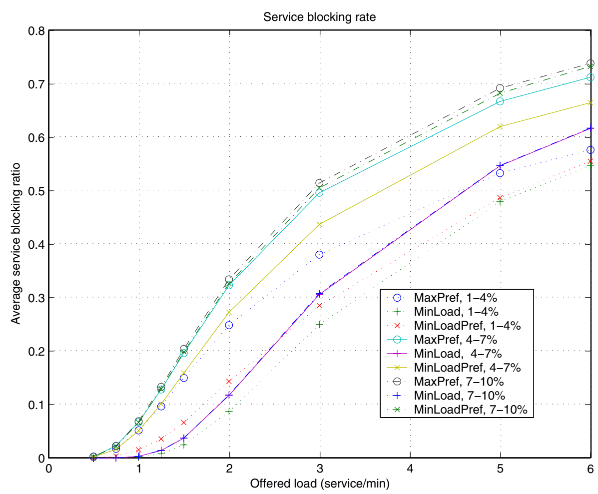

Fig. 5. Service blocking ratio for heterogeneity case III.

previous results to figure 4. The *MinLoad* approach shows the worse preference satisfaction ratio. Due to the higher resource availability, a DVB bearer is more likely to be established for receivers with both access devices, to reduce the load in the UMTS network. Since in half of the receivers with both NADs prefer UMTS, and the other half DVB in average always half of the receivers are satisfied according to their preference. The *MinLoadPref* approach bridges the gap especially for larger receiver groups, however looses performance with increasing service load.

Figure 5 shows the average service blocking rate for heterogeneity case III. Unlike in the previous case all receivers have both NADs available for service reception. Thus the selection of suitable bearers is only restricted by the unavailability of network resources. Consequently the *MinLoad* approach performs even better, allowing an up to 60% higher service load at the same blocking rate independent of the level of receiver interest in a service. It should be noted that based on our assumptions, a DVB network cell provides twice the amount of bandwidth of a UMTS cell. The significantly higher service load is achieved by more efficient utilisation of the DVB network resources by the algorithm. The *MinLoadPref* approach performs slightly worse than in case 2, since it has more opportunities to establish preferred bearers for a service due to the larger flexible set. Analogous results for user blocking are presented in figure 6. The improvement of the user preference rate can be witnessed in figure 7. At lower service load the user preference ratio is nearly the same for all rates of receiver interest. At higher service arrival rates, user preference can be in average better satisfied for larger receiver groups. Summarising the heterogeneity case III, it can be seen that both *MinLoad* and *MinLoadPref* are performing better than in case II. The observed increase in resource efficiency is due to higher flexibility of the receiver set and lower heterogeneity of the receivers.

The figures for case I have been left out in this paper, a more

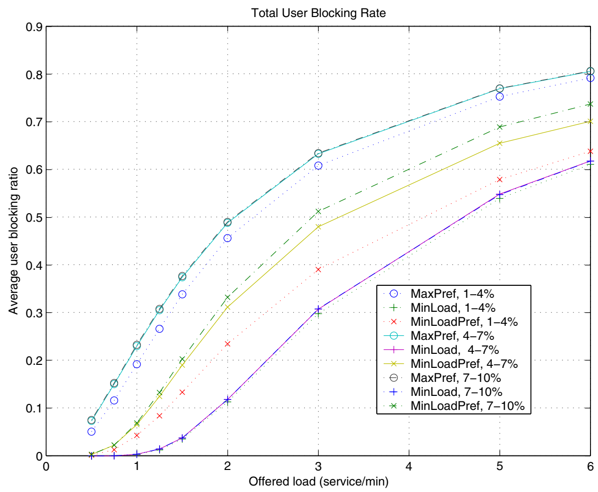

Fig. 6. User blocking ratio for heterogeneity case III.

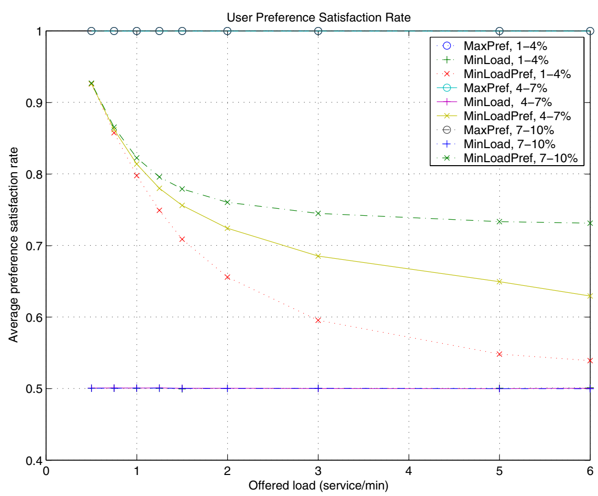

Fig. 7. User Preference Rate for heterogeneity case III.

detailed presentation of these results can be found in [14]. The performance for all three approaches are the same for the respective receiver interests. It is however not difficult to verify the results: as mentioned in III-D all approaches differ in how to operate on the flexible set of receivers, which is empty for the receiver heterogeneity case I.

V. Conclusion

This paper studied the problem of selecting the optimal bearer paths for multicast services with a group of heterogeneous receivers in wireless networks with overlapping coverage. We proposed a bearer selection algorithm, suitable for different optimisation goals and implemented heuristic solutions, concentrating on user preference and resource efficiency. Performance evaluations were undertaken, assuming overlapping UMTS and DVB networks. We showed that a carefully coordinated selection of multicast bearers over multiple access networks can significantly increase overall resource efficiency. We also demonstrated the existing trade-off between the different optimisation goals and provided a solution, bridging the gap between both opposing objectives.

The work presented in this paper considered bearer selection only for the ideal static multicast case, where users are not moving to different cells within the networks and multicast membership does not change during the duration of a service. Further investigations will include realistic receiver mobility models and the possibility that receivers may join in already ongoing sessions, or leave sessions before they end. Thus more adaptive algorithms need to be developed in order to respond to such a dynamic environment.

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References

[1] S. E. Deering, *RFC 1112: Host extensions for IP multicasting*. Internet Engineering Task Force IETF, Aug. 1989.
[2] T. S. G. Services and S. Aspects, *3GPP TS 22.146 V6.6.0: Multimedia Broadcast/Multicast Services (MBMS); Stage 1 (Release 6)*. 3rd Generation Partnership Project 3GPP, Sept. 2004.
[3] ——, *3GPP TS 23.246 V6.4.0: Multimedia Broadcast/Multicast Services (MBMS); Architectural and functional description (Release 6)*. 3rd Generation Partnership Project 3GPP, Sept. 2004.
[4] W. Tuttlebee, D. Babb, J. Irvine, G. Martinez, and K. Worrall, "Broadcasting and mobile telecommunications: Interworking - not convergence," in *European Broadcasting Union Technical Review*, Jan. 2003.
[5] T. S. G. Services and S. Aspects, *3GPP TS 25.803 V1.3.0: S-CCPCH Performance for MBMS,(Release 6)*. 3rd Generation Partnership Project 3GPP, Mar. 2004.
[6] "IST FP5 Convergence of IP-based Services for Mobile Users and Networks in DVB-T and UMTS Systems (CISMUNDUS) project website: www.brunel.ac.uk/project/cismundus."
[7] "IST FP5 Dynamic Radio for IP-Services in Vehicular Environments (DRIVE) project website: www.ist-drive.org."
[8] "Communication and Mobility by Cellular Advanced Radio (COMCAR) project website: www.comcar.de."
[9] "IST FP5: Moby Dick - Mobility and Differentiated Services in a Future IP Network project website: www.ist-mobydick.org."
[10] M. Inoue, K. Mahmud, H. Murakami, and M. Hasegawa, "Mirai: a solution to seamless access in heterogeneous wireless networks," in *ICC '03. IEEE International Conference on Communications, 2003. Vol 2*, 2003, pp. 1033 – 1037.
[11] "IST FP5 Spectrum Efficient Uni- and Multicast Services Over Dynamic Multi-Radio Networks in Vehicular Environments (OverDRIVE) project website: www.ist-overdrive.org."
[12] T. Lohmar, P. Casagranda, C. Gine-Sado, C. Janneteau, P. Seite, and Y. Tian, "Architectural issues for multicast group partitioning in mobile hybrid networks," in *IST Mobile Summit 2003, Aveiro, Portugal, 16-18 June 2003*. IST, June 16–18 2003, pp. 42–51.
[13] L.Huang, K.Chew, and R.Tafazolli, "Distributed resource management for interworking of cellular and broadcasting networks." in *13 th IST Mobile and Wireless Communications Summit 2004, Lyon, France*. IST, June 27–30 2004.
[14] A. Gluhak, *ICR-IoN-5.2.3: Multicast Bearer Selection for interworking Heterogeneous Wireless Networks*. Mobile VCE Core 3 Research Program, Dec. 2004.