Multicast/Broadcast opportunities in Beyond-3G Networks

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***Abstract*— In the Ambient Networks perspective of "Beyond 3G" scenarios characterized by the cooperation between heterogeneous networks consisting of different Radio Access Technologies, and from a radio resource management viewpoint, this paper defines a framework for future research in the field of multicast/broadcast service provisioning. In particular, multicast/broadcast services that are expected to arise in such scenarios are described, along with the service provisioning methods and radio resource management functions needed for their support. This work has been performed within the framework of the Ambient Networks project, belonging to the IST 6th Programme.**

***Index Terms*— Broadcast, Multicast, Radio Resource Management, Ambient Networks, Beyond-3G, 4G.**

I. Introduction

THE Ambient Networks (AN) project [1] aims at an innovative, industrially exploitable new network vision based on the dynamic composition of networks (ANs) to avoid adding to the growing patchwork of extensions to existing architectures. This will provide access to any network, including mobile personal networks, through instant establishment of inter-network agreements. The project adopts the design paradigm of horizontally structured mobile systems that offer common control functions to a wide range of different applications and air interface technologies. Such a radical change requires the definition of new interfaces and a multitude of standards in key areas of future media- and context-aware, multi-domain mobile networks.

The AN project considers Radio Resource Management (RRM) techniques as in [2], capable of establishing and coordinating transmissions over multiple Radio Access Technologies (RATs) in parallel and/or multi-hop fashion, even considering diverse business scenarios.

Such a heterogeneous scenario will have impact on Multicast/Broadcast (M/B) services with respect to the new possibilities of service delivery that AN will provide. The end-user will experience higher availability of added-value services, while the overall network will gain from improved resource efficiency†.

Previous art of 3GPP with respect to QoS classification [3] and M/B services [4][5] is considered as a baseline and reference for the work within this paper.

The paper starts with a first-stage description of M/B fundamentals and services in II and III, including an M/B service classification. Suitable M/B service provisioning methods along with proper RRM solutions and strategies are then analysed in IV and V. M/B characteristics of beyond-3G RRM, needed to support these service provisioning methods, are then collected in VI.

II. Multicast/Broadcast fundamentals applied to AN

In principle, suitable definitions of multicast and broadcast in the AN framework could be as follows:

- *Multicast*: transmission towards a specific group of users in a given Service Area.
- *Broadcast*: transmission towards all users in a given Service Area.
- *Service Area*: The coverage area defined by the set of possibly different RATs and hops over which the service is intended to be provided (including cellular, digital broadcasting, hot-spot, etc.).

It should already be noted that although the notion of Service Area currently represents a geographic area for service delivery, concepts such as multi-domain and moving networks might impact the definition of Service Area, which in Beyond-3G might better correspond to a set of domains, and/or to a moving service area consisting of multiple RATs and hops.

Multi-RAT and multi-hop capabilities together allow reaching different end-users as required, in parallel and/or in sequence. This can be used to transmit the M/B service with

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† Note: security and charging are not dealt within this paper.

possibly different QoS over different RATs‡, to select RATs and hops depending on the most resource efficient solution, to reach otherwise unreachable users, or even to reduce service cost.

Multicast/broadcast transmissions can consider:

- *Dedicated channels*, which generally achieve resource efficiency via fast adaptation of the radio channel to the two-party transmission.
- *Common channels*, where a single transmission is targeted to more than one end-user device.

To serve a given user or group, both kinds of channels could be used within multi-hop and/or parallel transmissions.

Management of M/B services has generally the objective of providing the given content to the end-users, with the desired QoS, the least possible resource consumption and/or associated costs.

III. Multicast/Broadcast Services in B-3G networks

GSM was originally designed for voice services, while UMTS was designed for a wider range of unicast services. Digital radio and TV, regarded as broadcasting systems, were designed only for (broadband) M/B over large areas. However, none of the existing telecommunication systems was originally designed for both unicast and M/B services.

M/B studies for beyond-3G networks should start from the identification, definition and description of possible multicast/broadcast services to be delivered. This step is necessary in order to define which services need to be supported by beyond-3G RRM.

3GPP service concepts (which QoS classification can be found in [3]) already identify two service categories that are applicable to M/B: *streaming* (typically a guaranteed and constant bit-rate transmission) and background (here called '*download*', typically a transmission with non-guaranteed bit-rate that could be interrupted and resumed).

Considering 3GPP concepts, but departing from them, we propose here for M/B services the following classification:

- *No-delay streaming*: streaming services (e.g. breaking news, video-goals, scheduled TV programs) that need to be transmitted as soon as possible either when they become available, or at a scheduled time. No (or very low) tolerance to delays, tolerance to data errors.
- *Streaming*: streaming services (e.g. streaming of news and events) which should be transmitted simultaneously in the whole service area, while possibly being re-scheduled and delayed. Tolerance to data errors.
- *Download*: download services (e.g. download of audio and video files) which can be transmitted at different times in different parts of the service area. Tolerance to delays and data errors.
- *Error-free download*: download services (e.g. software updates, file download) which can be transmitted at different times in different parts of the service area. Tolerance to delays, but no tolerance to data errors, which is typically achieved by retransmissions. Retransmissions can even use M/B mechanisms.

‡ E.g.: different QoS may be used over UMTS in the city and GSM outside, or even over 4G for mobile users and cable for fixed users in the light of fixed-mobile convergence.

Even if the presented service classification is not exhaustive and a number of mixed scenarios could exist (*hybrid services*), we go here through these classes in order to identify suitable service provisioning methods over the multi-RAT/multi-hop service area, with the goal of devising RRM needs for Beyond-3G networks.

A. No-delay streaming – class 1

For this service class, a resource needs to be available for transmission over the whole service area, so that the service can be transmitted as soon as possible when it becomes available, or at the scheduled time.

These transmissions would therefore take advantage of a resource that is reserved with pre-emptive priority to this service class.

In case the exact time when these services or contents are going to become available is not known a-priori, a preventive resource planning strategy will allow transmitting the content as soon as possible. On the other hand, preventive resource planning strategies will also allow transmission of services that are scheduled well in advance (e.g. TV programs).

Different reservation strategies for the service are possible such as:

- Other services with low QoS requirements or which QoS can be downgraded may use the reserved resources when not used by class 1. When class 1 services will require regaining use of those resources, these other services will be stopped or their QoS downgraded (considering their minimum QoS requirements).
- Dynamically adapt reservation according to available RATs (which in some scenarios may change due to mobility, AN composition agreements etc.).

Furthermore, different resources could be reserved for different class 1 services, as well as class 1 services of different priority may use the same reserved resource, therefore possibly requiring to be transmitted one after the other (which may be an exception due to lack of resources).

B. Streaming – class 2

For this service class, a resource needs to be available for transmission over the whole service area.

Audio and video streaming, as well as streaming of textual information, could make use of this service class, which will be generally characterised by a constant bit-rate. Class 2 is suitable at least for those streams which transmission cannot be planned in advance and which delivery can be delayed.

For class 2, a resource reservation process could start either:

- when the service becomes available for transmission,
- Before the service becomes available if this event can be foreseen.

In order to free-up resources to be used for these services, a possibility is to redirect ongoing connections towards other RATs. Note here that this concept could be applied also for class 3 and class 4 services.

While waiting for the service or the resource to become available, all resources already reserved could be used for services of lower priority and/or QoS.

It should be noted that there could exist the case where the necessary resource cannot be reserved within a reasonable amount of time without interrupting the ongoing transmission of some guaranteed bandwidth user service. This implies drawbacks with respect to the waiting time for resource availability and/or interrupted guaranteed bandwidth users.

The statistic relevance of such drawbacks depends on the service area extension, RAT and cell properties and ongoing service characteristics (duration, resource consumption, etc.). In case these drawbacks would become stringent for a given service, it could be considered to use class 1 instead.

C. Download – class 3

For this service class, a resource needs to be available at least over a part of the service area (sub-area). It should be noted that download services may either be requested by the user, as they may be pushed by the network.

A class 3 service may be transmitted in different sub-areas in different times according to resource availability. This means that free resources in different sub-areas can be used for M/B services instead of remaining unused while waiting for the resource to become available in the whole service area. RRM algorithms may need to select which alternative RATs are preferred for transmission within a given sub-area.

Transmitting the service in different sub-areas in different times implies however that a user may miss the service due to mobility between them. In order to overcome this:

- The time between transmissions in the different sub-areas could be kept as short as possible.
- The class 3 service could be transmitted in different partially overlapping sub-areas.

It could also be useful to poll the users in the service area, in order to decide whether further transmissions are required. A user may respond to the polling if the content was not received, or even if it was received incomplete due to mobility. A class 3 service may be transmitted up to a certain number of times, and/or up to a certain time, also depending on service characteristics and details.

Users that receive the content more than one time could combine the received data for error correction purposes.

D. Error-free download – class 4

For this service class, a resource needs to be available at least over a part of the service area (sub-area).

As for class 3, a class 4 service may be transmitted in different sub-areas in different times according to resource availability, leading to the same benefits.

Retransmissions could be based on explicit signalling from the users, which could request missing frames or packets.

Specific retransmissions may take place in unicast or M/B transmissions if targeted to more than one user.

Retransmissions may also take place over different RATs and hops, e.g.: a user may retrieve missing packets from a nearby user who instead received the content correctly.

E. Hybrid services

Services using combinations of the previous service classes or their characteristics are possible. An example is a service using class 2 transmissions at first, and then making corrections thanks to class 3 transmissions. Another example is a service using class 3 transmissions for a number of times, and then refining the transmitted content through dedicated corrections made with class 4 transmissions.

IV. ADVERTISING, JOINING, POLLING AND TRACKING

In this section we investigate a number of M/B service provisioning issues, namely: advertising, joining, polling and tracking.

A. Advertising

An M/B service may need to be advertised before being transmitted. This advertisement may very well be an M/B transmission itself, and potentially trigger interaction with the user such as joining the advertised service, requesting more details of the advertised service or requesting advertisements of similar services.

Service advertisements might be sent over different RATs and hops. These messages may indicate how the service will be delivered through the different RATs and hops, i.e.: whether RATs and hops are chosen a-priori or dynamically, or whether a negotiation should occur over a specific RAT.

The area where advertising is performed may not correspond to the service area intended for M/B service delivery both geographically due to mobility and/or in terms of coverage due to the presence of multiple RATs.

B. Joining

It could be useful to request the users to join a service in order to be able to receive the service later on. The joining procedure could provide the user with appropriate decoding keys, and/or it could be a mechanism for tracking the users.

However, even in the case of multicast the joining is not strictly needed, since a multicast transmission could be made as an encrypted broadcast transmission where only the intended users will be able to decode thanks to some other mechanism through which keys can be exchanged.

Joining messages could be sent through different RATs as well as they may be relayed through multiple hops, even outside the service area.

C. Polling/Tracking

Simply knowing the number of interested users is not sufficient: their RAT capabilities and radio conditions are also important to decide which are the most appropriate RATs, multi-hop routes and channel types (common/dedicated) for transmission. For these reasons it is typically useful to poll the users that are interested in receiving the content. To be noted that polling would also be useful for broadcast transmissions both due to the multi-RAT and multi-hop environment, and to avoid transmitting any content if there are no listening users.

There is of course a trade-off between the signalling that would be needed for polling (including the time and delay that it implies) and the actual resource savings that it can bring. This trade-off depends on the specific network scenario.

A similar result could also be obtained through a ‘tracking’. In this case, before the service becomes available for transmission, interested users are polled, and their status and ‘reachability’ within the network are tracked over time. By doing so, when the service becomes available for transmission, the network could already have all information needed to decide on the most suitable RATs and hops.

Potentially, networks could exist where M/B services are delivered through fast, optimal and dynamic coordination of all possible RATs and hops. However, such a solution would likely imply a relevant signalling load and complexity on the polling/tracking mechanism, therefore being suited for relatively small networks, while not representing a scalable solution as such. Modularity would be needed in order to make this solution applicable to large networks.

V. M/B FLOW TRANSMISSION: AN ILLUSTRATIVE EXAMPLE

Session and flow management features of beyond-3G RRM need to be multicast/broadcast capable in a multi-RAT and multi-hop environment, supporting the described M/B service provisioning methods.

Considering the described framework, Figure 1 provides an elaborated illustrative example of M/B flow transmission, which main related issues are then investigated. The following notation is used:

- Any ‘oval’ represents a generic AN, which could be an operator server, an infrastructure relay node, a user terminal and even more, as the AN approach is designed to be applicable to any network configuration.
- Every line represents a Radio Access (RA), which here identifies a link of any possible RAT.
- The flow is transmitted from the M/B source downwards to the receivers.

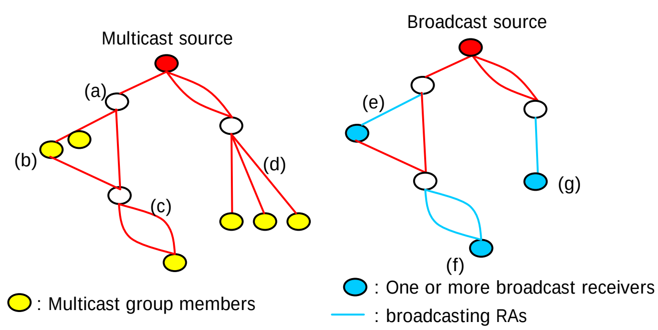

Figure 1: M/B flow transmission examples

When transmitting M/B flows, the multicast group members or the broadcast receivers might be reached in parallel, or in sequence in a multi-hop fashion. Each end-user may receive the flow through one or more RAs, as well as it may forward it towards further destinations.

Making a major step from the 3GPP concept of M/B [4][5], beyond-3G RRM enables a number of supporting features (e.g. multi-RAT, multi-hop) that make the M/B transmission in Ambient Networks a complete distribution tree. With reference to Figure 1, the following considerations apply:

(a) In the distribution tree some ANs can function as repeaters only, not belonging to the target multicast group or to the intended broadcast receivers, but possibly transmitting on one of the target broadcast RAs. These ANs can have economical interest in functioning as relays, while they might not be able to decrypt the flow they are repeating.

(b) Multiple multicast group members can receive the flow via the same RA through common channels (represented in the picture as two ANs hanging on the same RA). Some of these members may also function as repeaters towards other multicast group members, e.g. due to particular access capabilities or other agreements.

(c) A multicast group member can receive the flow from two different RAs in multi-radio (or even multi-route) diversity.

(d) Each multicast group member within the same RAT and ‘cell’ can receive the flow via different RAs through dedicated channels (here specified at the bearer level, and represented by the different lines), e.g. when this leads to greater resource efficiency.

(e) The broadcast objective in a multi-hop scenario is in principle to reach the selected broadcasting RAs (that belong to the service area) from which broadcast will be performed. However, in beyond-3G RRM, specific broadcast receivers may need to be known and selected for the purpose of forwarding a flow towards the target RAs[§]. Depending on the specific setting, economical benefits may also be foreseen for the forwarding receiver.

(f) Some broadcast receivers can combine the transmissions from different RAs, while others may not, e.g. due to capability limitations or because it is not convenient.

(g) While a broadcast is normally performed through common channels (as depicted in Figure 1 with the single RA towards “One or more broadcast receivers”), beyond-3G RRM broadcasts can also use dedicated channels, e.g. for reaching relay ANs, for reaching relaying broadcast receivers, or for resource optimisation purposes.

[§] Note that differently from 3GPP, some broadcast receivers need to be known, and dedicated channels are possible also for broadcast transmissions (as from point (g)).

VI. M/B CHARACTERISTICS OF BEYOND-3G RRM

Having devised different service provisioning methods for different M/B service classes, we summarise here the main characteristics of beyond-3G RRM functions for M/B support, from both distribution side and receiver side.

A. *Distribution side*

With distribution side we mean the M/B source as well as any potential AN node or receiver functioning as a relay towards further receivers. The distribution side RRM should be able to:

- Operate on a service area definition that accounts for multiple RATs and hops, as well as multiple domains and moving networks.
- Use resource reservation strategies (r.r.s.), including:
    - Fixed r.r.s.: resources are reserved a-priori over the selected RATs and hops on the whole service area, even well in advance.
    - Dynamic r.r.s.: resources are reserved dynamically over the selected RATs and hops on the whole or part of the service area, depending on the actual users and their characteristics.
    - The possibility to use the reserved resource for other services (even non-M/B) with non-guaranteed QoS.
- Identify spare resources in sub-parts of the service area for transmission of M/B service content in those areas.
- Advertise the M/B service through possibly different RATs and hops, with potential user interaction.
- Poll the involved users over possibly different RATs and hops, either:
    - Just before transmission (polling).
    - In advance, keeping memory of the status over time (tracking).
- Poll the users in the whole or part of the service area in order to know whether M/B transmissions of the whole or specific parts of the M/B service content are still required. This may also be initiated by the user.
- Transfer ongoing sessions to available RATs in order to free up resources to support a pending M/B service.

B. *Receiver side*

The receiver side includes the intended destinations of content delivery (e.g. users, sensors, etc.), plus any potential AN functioning as a relay towards further receivers[**]. The receiver side RRM should be able to:

- Join the service through possibly different RATs and hops, independently from the side where this is initiated.
- Require transmission of the whole or specific parts of the M/B service content (e.g. some packets or frames).
- Combine different transmissions over possibly different RATs to improve the quality of the received content.

[**] Note: as visible in Figure 1 ANs exist which are receivers and distributors at the same time.

VII. CONCLUSIONS

This paper focuses on multicast/broadcast RRM issues in beyond-3G networks, within the wide and general approach of Ambient Networks conceptual framework. Therefore we assume the AN paradigm where “everything is an AN”, we abstract from any specific RAT and we consider all characterising AN features such as multi-access and multi-hop.

Trying to use a similar approach to 3GPP, but departing from it, M/B services have been described and classified in No-delay streaming, Streaming, Download, Error-free download, and Hybrid services. Furthermore for these classes, suitable service provisioning methods including resource reservation strategies, resource optimisation issues and retransmission schemes for AN have been discussed.

M/B service provisioning issues (such as advertising, joining and polling/tracking) along with M/B flow transmission have been applied to the AN world and discussed in such an heterogeneous context, deriving key RRM characteristics for M/B support at both Distribution side and Receiver side.

It should be noted how the difference between *multicast* and *broadcast* tends to vanish, as the heterogeneous multi-hop and multi-RAT environment forces to reconsider whether a broadcast could be done in more efficient ways through coordination of all the available resources.

Not only, the very basic definition of *service area*, which is currently known to represent a geographic area for service delivery, will need to be extended, as in the AN framework it might correspond to a more generic domain, as it could be a moving service area consisting of multiple RATs and hops.

Our future attention will be focused on further development of the described concepts in different scenarios, including service classification and description, along with RRM techniques such as resource reservation, service provisioning and resource optimisation strategies.

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