Project acronym: CONCERTO

Project full title: Content and cOntext aware delivery for iNteraCtive multimEdia healthcaRe applications

Grant Agreement no.: 288502

Deliverable 2.3

Cross-layer signalling

Contractual date of delivery to EC	T0+24
Actual date of delivery to EC	29/11/2013
Version number	1.0

Lead Beneficiary	VTT
Participants	VTT, CEFRIEL, TCS, CNIT

Dissemination Level:	PU
Nature:	R
Total number of pages	34

Keywords list:
Cross-layer signalling, system architecture, networking, network information service, distributed decision making

Executive Summary

Cross-layer signalling is widely cited as very potential way to improve overall network performance and cooperation of different network layers and entities in the network infrastructures. In principle, without cross-layer signalling solutions, reliable and fair Quality of Service (QoS) guaranteed networking across the Internet is difficult to realize, much less about Quality of Experience (QoE) controlling. The cross-layer signalling solutions are used, for example, for traffic adaptation, network resource sharing adjustments, mobility decisions, and to improve robustness. All these mechanisms impact the service quality experienced by the end-users and, thus, making cross-layer signalling an important part of the CONCERTO's use cases. The substantially increasing demand on wireless network capacity will bring many challenges for the future's mobile networks, which also compels mobile network operators, to find solutions for a better utilization of the existing network infrastructure and resources. This will make the cross-layer signalling even more essential part of seamless and efficient wireless networking.

This document presents the studied cross-layer solutions for the CONCERTO project targeting to improve the networking experience of telemedicine services and finally propose a solution to be adopted. Two distinct solutions are studied, an event dissemination based Distributed Decision Engine (DDE) framework and a network information service (NIS) working as a query basis. The DDE is suitable for frequent event dissemination between different layers of different entities. The information service provides more slowly varying or static information about networks and access points. This information can be accesses through information queries when needed, rather than using an event based signalling where information is sent upon changes in the environment or data. The final solution proposed by CONCERTO is a combination of these solutions.

TABLE OF CONTENTS

EXECUTIVE SUMMARY 2

1 INTRODUCTION 5

2 CONCERTO CROSS-LAYER SYSTEM ARCHITECTURE 6

2.1 OVERALL CROSS-LAYER SIGNALLING ARCHITECTURE 6
2.2 ACCESS NETWORK SIGNALLING 10
2.2.1 Distributed Decision Engine Message Exchange 11
2.2.1.1 Event message 11
2.2.1.2 Registration/UnRegistration messages 12
2.2.1.3 Subscription/UnSubscription messages 12
2.2.1.4 Redirect message 12
2.3 INTER-DOMAIN RESOURCE INFORMATION SIGNALLING 13
2.3.1 Cross-layer signalling management 14
2.3.2 Cross-layer signalling use cases 15
2.3.2.1 Cross-layer information producer and consumer in different domains 15
2.3.2.2 Resource information producer and consumer in the same domain 15
2.3.2.3 Resource information already available from an external database 16
2.4 NETWORK INFORMATION SERVICE 16

3 USE CASES FOR CROSS-LAYER SIGNALLING ARCHITECTURE 20

3.1 CROSS-LAYER INFORMATION FORESEEN IN DIFFERENT FUNCTIONALITIES 20
3.2 CROSS-LAYER SIGNALLING IN CONCERTO USAGE SCENARIOS 23

4 CROSS LAYER IMPLEMENTATION IN SIMULATOR AND DEMONSTRATOR 26

4.1 SIMULATOR 26
4.2 DEMONSTRATOR 26

5 IMPROVING INFORMATION SERVICE USABILITY FOR CELL SELECTION 28

6 CONCLUSIONS 31

7 REFERENCES AND GLOSSARY 32

7.1 REFERENCES 32
7.2 GLOSSARY 33

LIST OF FIGURES

Figure 1 – DDE Framework. 6
Figure 2 – CONCERTO's cross-layer signalling architecture based on AG/DDEs 9
Figure 3 – DDE as an Access Network Signalling Enabler 11
Figure 4 – An example of DDE framework message flow 11
Figure 5 – Overview of Network Information Service 18
Figure 6 – NIS architecture 19
Figure 7 – NIS to provide information about access points in range 23
Figure 8 – DDE event reporting to indicate the received quality to the video transmitter 24
Figure 9 – Inter-domain resource events for finding assisting network access relays 25
Figure 10 – DDE implementation in the simulation chain. 26
Figure 11– Cross-layer signalling in the demonstrator 27
Figure 12 – Distribution of cells in range in S1 29
Figure 13 – Distribution of cells in range in S2 29
Figure 14– Distribution of cells in vicinity in S2 30
Figure 15 – Cell size improved mobility 30

LIST OF TABLES

Table 1 – Example Information Element Content of IEEE 802.21 Information Service 17
Table 2 – Source and consumer of cross-layer information in different functionalities. (i) = in-band signalling 21

1 Introduction

Telemedicine applications often have stringent requirements for the network quality they are used over. Fast evolution of wireless mobile networks has enabled the application to be used, basically, anywhere and anytime. However, especially, when using the commercial and publicly available wireless networks, their resource availability and capability to serve the mobile stations connected can greatly vary. The demand for wireless network capacity is anticipated to substantially grow in the future and mobile network operators already face big problems to keep up with sufficient capacity. Moreover, different networks have different capabilities and radio signal propagation also introduces additional challenge for the network. The propagation is sensitive for the environmental changes, affecting the reliability of wireless networks. Thus, although the wireless networks have evolved and their capacities significantly increased, there is need for mechanisms for a better utilization of the network resources and optimizing the services according to the available resources. Here, cross-layer signalling solutions are in a crucial role.

The CONCERTO project fosters the utilization of wireless networks for telemedicine applications and provides solutions to bring a hospital and remote emergency areas closer. Live connection from an emergency scene to the respective hospital allows fastening and developing the overall handling of emergency cases. For example, the hospital side can see in real-time what has happened in the accident scene and possibly consult the ambulance crew and make appropriate preparations in the hospital side before the patients arrive. Moreover, the route from the emergency scene to the hospital can be long, and the same connection could be maintained also during the driving phase. All this require high and consistent performance from the employed wireless networks, which is not always the case in practice. Thus, for example, the used services may require adaptation to the prevailing network conditions and finding the most potential networks and access points for the services is needed. Cross-layer signalling solutions provide a prerequisite for these actions.

The CONCERTO cross-layer signalling architecture comprises two different mechanisms to attain sufficiently extensive cross-layer signalling possibilities, namely Distributed Decision Engine (DDE) and Network Information Service (NIS). These two mechanisms form the basic structure of the cross-layer signalling architecture proposed and will be used in addition to already existing signalling and feedback mechanisms (such as SNMP, RTCP, lower layer protocols, etc.). The purpose of the proposed solution is to extend the existing controlling mechanisms by providing a unified signalling architecture for accessing such information that cannot be accessed by using existing controlling mechanisms. The purpose of the proposed architecture is not to replace the existing mechanisms but to extend the usage of cross-layer information in functionalities which do not have yet mechanisms for accessing all useful information from different system layers.

DDE is an event based signalling solution, which works on an event registration and subscription basis. Different network entities can register events to the DDE carrying information they see as interesting for other network entities, either remote or local. The DDE is suitable for information that changes and expires relatively fast. DDE can also be used, e.g. to find supporting mobile stations (MSs) nearby to assist in the transmission. In the CONCERTO cross-layer signalling architecture, the DDE is used within an access network but also between different administrative network domains, being divided according to geographical division or operated by different network operators.

NIS is for delivering static or rarely varying information to the interested entities. As the information does not frequently vary, NIS works as query basis. When, e.g. a MS needs information the NIS provides, it sends a query for this information. The information comprises overall information about networks and their access points. Based on this information, MSs can, for example, assess the networks in range and select the most optimal one. In the CONCERTO architecture, the NIS is proposed to be enhanced also with the coverage areas of base stations (BSs). This enables to more accurately determine the BS cells that can serve the MSs. This document also summarises a published study about the benefits of coverage area database in BS cell selection.

Overall, the CONCERTO cross-layer signalling architecture aims to provide an extensive and flexible solution for responding to a variety of state-of-the-art cross-layer optimization requirements. In addition to cross-layer signalling, existing control signalling and feedback mechanisms can be used to control end-to-end communication in parallel with the proposed solution. The proposed cross-layer signalling architecture is designed to extend the existing controlling mechanisms to enable improved usage of network resources and more reliable communication, not to fully replace existing controlling mechanisms.

2 CONCERTO cross-layer system architecture

2.1 Overall cross-layer signalling architecture

The first specification of CONCERTO's cross-layer signalling architecture reported in D2.2 [1] presents mainly two concurrent and complementary solutions. The first solution introduces the DDE, an evolved event delivery framework from the Triggering Framework [5] utilized in the FP7 ICT OPTIMIX project. Another solution is the NIS. Overall, DDE provides dynamic information about a resource (e.g. configuration setting, status, measurement) by events dissemination between different architectural entities (system layers or network equipment). The information can come from any protocol layer, but the focus is primarily on the access network. NIS, instead, provides more slowly time-variant or even static network information, such as related to available wireless networks and associated access points. Due to the relatively static information, NIS is commonly defined to be based on information queries, not on subscription based information delivery system. A possible NIS deployment architecture discussed in Section 2.4 targets to a scalable solution allowing query based function. This component should be introduced in each operator network and the cooperation between different NIS servers is important to be allowed. Overall, the NIS can be perceived as a complimentary solution for other cross-layer signalling mechanisms, facilitating heterogeneous networking.

The DDE is based on a publish/subscribe approach. Basically, three elements compose the DDE, as illustrated in Figure 1: the event producer that registers with the DDE and provides information, and the event consumer, which subscribes to the DDE for a specific set of information, and the event caches, which stores and manages the resource information exchanges. Algorithms shown in the figure can be considered as event consumer producing decision events. Basically, when the producer sends an information update, namely event which the event consumer has subscribed to, the event cache disseminates this piece of information to the consumer. The communication between the DDE elements lies on the TCP protocol, enhanced as needed with data validity fields and digital signature, for example. DDE functionalities are introduced with more details in D2.2.

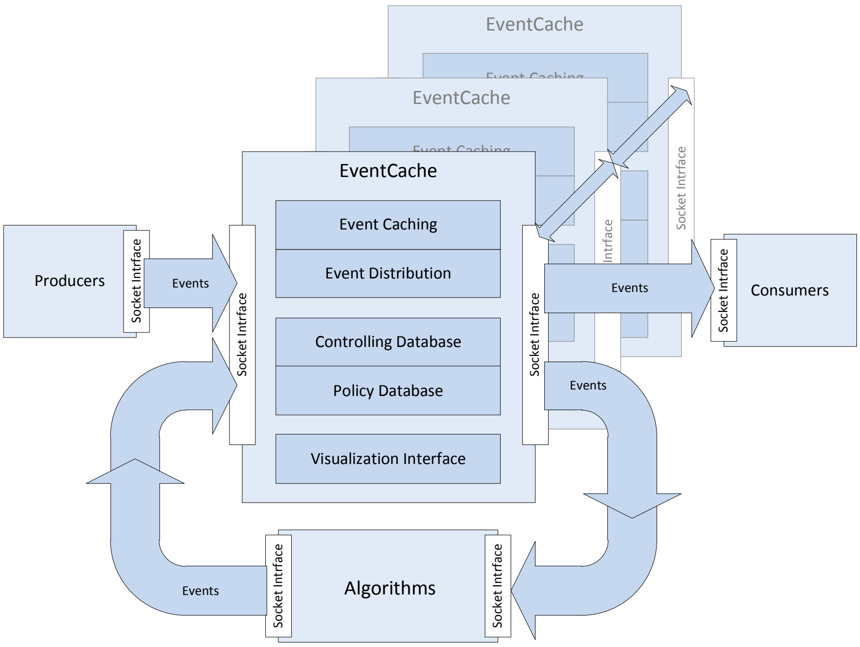

Figure 1 – DDE Framework.

The role of collection points of resource information in the overall architecture is covered by the Access Gateways (AGs) residing in each domain. One of them should be promoted to act as border gateway (BG), allowing interfacing with other domains, in practice providing reference information about the resources available in its own domain and receiving reference information from the other domains. Each AG has a DDE event cache in order to store and manage the collected resource information. NIS can also be located at the AG, in order to collect and make slowly time-variant or static information efficiently available.

Figure 2 depicts the CONCERTO overall architecture with details of cross-layer system architecture including two network domains for a general view. The overall architecture has been introduced also in D2.2 with more details and mapping between the architecture and CONCERTO use cases. The AGs and DDEs have been integrated in the cross-layer architecture. In the figure, in each domain there are two AGs/DDEs for each attached access network, while there is also at least one NIS in each domain. The NIS can be a separate server or possibly co-located with an AG/DDE. By considering the actual network extension and scenario relevant for the CONCERTO's use-cases, a single AG/DDE is likely enough to manage the issue and exchanged cross-layer signalling information. Since reliability (actually supported by at least two AGs) can be taken for granted, and the network distance between producer and consumer entities is limited, the presence of multiple AGs in the trial/evaluation scenarios is not justified.

An AG/DDE has the following features:

- An event message routing functionality to directly provide the cross-layer resource information to the requesting/subscribed consumer if it receives/holds such a piece of information
- An indexing functionality, allowing the AG/DDE to find, if necessary, the requested information as generated and managed in a different domain (or in already existing external database)
- An algorithm module, which allows validating, filtering, processing the collected and which takes resource information as input (including aggregation of it if needed) according to defined rules and policies
- An event cache that records and stores produced events for their validity duration (according to a "time to live" parameter specific to each piece of information)
- Support for an event and reference information distribution to other AGs in the same domain and also to the BGs of the other domains
- A policy database
- A controlling database

The overall CONCERTO architecture illustrated in Figure 2 can be divided into three main sections from the cross-layer perspective; access network, transit network and the emergency coordination centre. Each of these sections needs solutions for cross-layer signalling which can be handled by utilizing the proposed cross-layer architecture and solutions.

An access network is a network which MSs use to connect their service providers. In the scenarios defined in CONCERTO, the access network is usually wireless network such as 3G/LTE/WiFi. Wireless access networks have several challenges related to QoS, mobility and resource allocation and cross-layer signalling can be used to tackle the challenges. Within the access network, the cross-layer signalling (XL data in the figure) is mostly related to information and event exchange between an MS and a BS. In an access network, there can be a DDE entity deployed to handle access network related signalling, as discussed more in Section 2.2. A direct cross-layer signalling between the base station and mobile terminal connected is a reliable and particularly efficient way to improve communication in the access network. In CONCERTO architecture, access networks are mainly considered at the sender-side which can be for example an ambulance in the emergency scenarios described in D2.1 [2].

Transit network is a part of the network which is used to transit the traffic between the end-users and their access networks. Transit network can be seen as a federation of networks or a set of access networks and a core network, depending on the specific case. Overall, transit network as a whole can be understood as the Internet. Regarding CONCERTO's use-cases, a single domain (including a transit-core network and some wired or wireless access networks at both the emergency area and the hospital premises) can be considered. Transit network has different kinds of requirements for cross-layer signalling compared to access networks such as cross-layer information exchange within the transit network and between domains. Transit network signalling is mostly related to the resource information exchange between different network domains, divided into domains based on geographical regions, administrative areas and/or different network operators. An NIS server can be deployed to each network domain, as illustrated in the figure, or alternatively each access network can also have an NIS server.

In addition to access network and transit network, the emergency coordination centre (or crisis centre) can be considered as one of the main parts of the architecture which affects cross-layer signalling especially in use cases related to emergency situations and ambulance. As stated in D2.2, the emergency coordination centre is responsible to coordinate all the received data and, taking into account the requests of the doctors, can prioritize different fluxes of data or ask to the senders in the emergency area to adapt their transmissions, the compression of the sent data and the kind of data transmitted. Adaptation can also be decided directly by the senders according to the cross layer information received, while not badly affecting the overall network efficiency. Due to the importance of emergency coordination centre, one of the cross-layer signalling elements, DDE, introduced later should be also included in the emergency coordination centre (ECC), in addition to other locations within the networks. By using this approach, data flow(s) between the emergency area / ambulance, coordination centre and the hospital(s) can be efficiently controlled and secured by utilising cross-layer information.

In the following chapters we will describe different sections of the proposed cross-layer architecture by first introducing the solution for access network signalling and especially DDE. After this we will describe the solution for transit network or inter-domain signalling and finally we will introduce network information service.

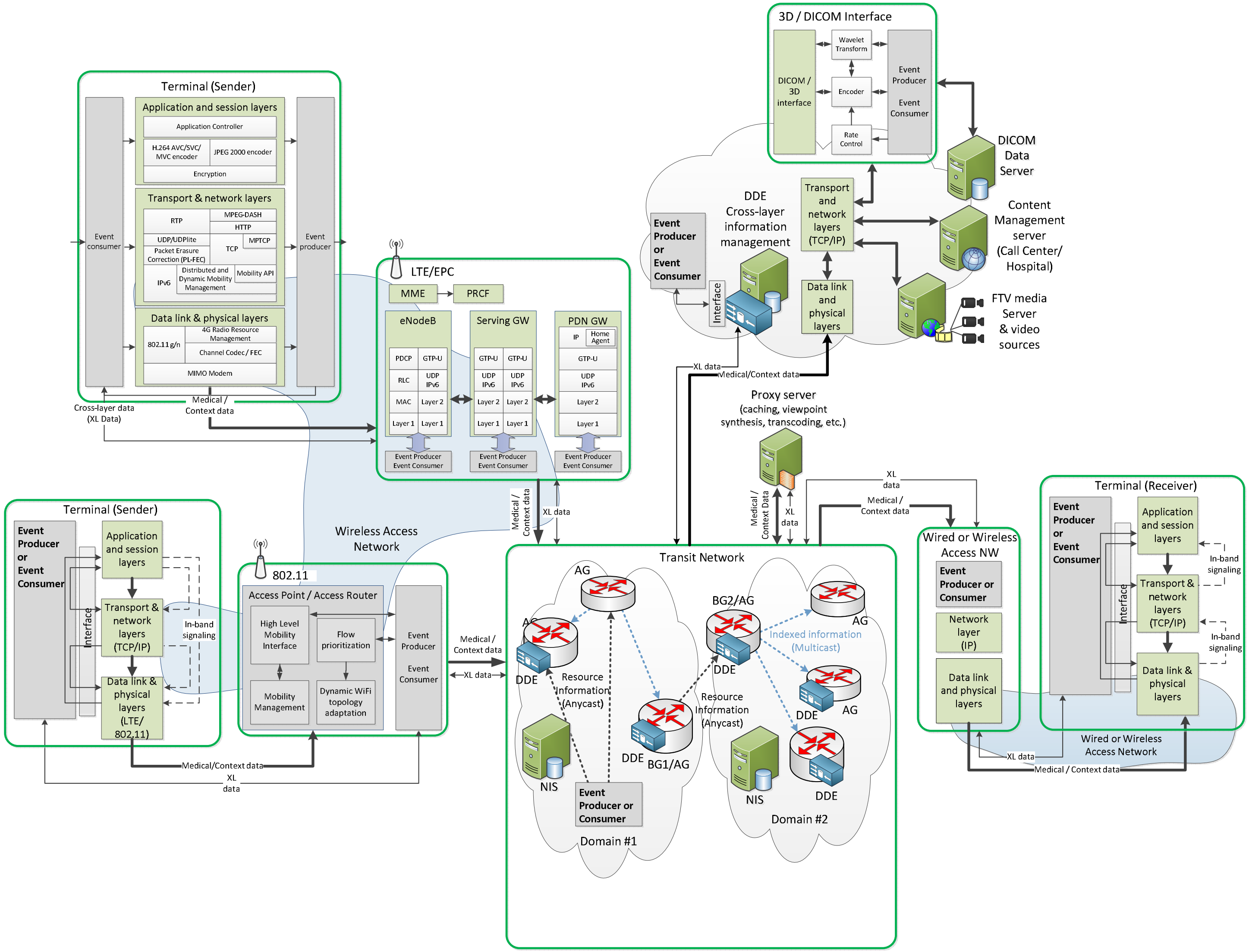

Figure 2 – CONCERTO's cross-layer signalling architecture based on AG/DDEs

2.2 Access network signalling

Most of the overall signalling happens within an access network. When a mobile station (MS) monitors its current link and network condition, it mostly uses signalling between the BS and the MS. For example, a fair and reliable service prioritisation at the BS MAC layer requires knowledge about services and the current statuses of these services in their respective MSs. A direct cross-layer signalling between the BS and MS connected is a reliable and particularly efficient way to get known of these factors. MSs can also monitor their link condition based on the events received from the BS it is affiliated with.

The event delivery between the MS and the BS can be efficiently carried out with the solution developed in the FP7 OPTIMIX project. There, a Triggering Engine (TRG) was running in both the MS and the BS for a flexible event delivery. In this solution, the local event producers and consumers use the services of the local TRG only and TRGs in different entities handle the remote event signalling. For example, the event produced by, e.g. application layer in the MS is sent directly through the TRG in the MS to the TRG in the BS, which delivers the event to the entity in the BS which subscribed to this event. The DDE solution can also be used for this type of signalling, however, it requires that the MS and the BS run DDE services. TRG and DDE are compared in more details in Deliverable D2.2 [1]. Moreover, the IEEE 802.21 event service provides a standardized solution for the event delivery between MSs and BSs, also considered in the OPTIMIX project. In CONCERTO, Information Service part of the IEEE 802.21 is studied and included in the cross-layer signalling architecture for static and slowly changing information while the Information Service was not studied in the OPTIMIX project. The DDE is used to provide a generic signalling solution for more rapidly changing information.

Most of the user mobility happens within a single access network. By using the DDE framework, the BSs can communicate about the load balancing with a cross-layer signalling solution and MS can subscribe to events from the access points within the whole access network regarding the access points in its vicinity. Based on these events, the MS can assess the available accesses with the currently employed one.

The DDE solution provides an efficient and distributed solution to perform cross-layer access network signalling. Figure 3 illustrates an access network with several BSs and a few supporting WLAN access points. Each network entity comprising the access points, mobility and load balancing servers, and MSs can subscribe to events of interest and produce events for the other entities. The network can possibly be equipped with more than one DDE in order to mitigate the load balancing issues and improve the reliability of the signalling service.

As the DDE is implemented to be a flexible signalling solution for a variety of use cases, also other than those considered in the CONCERTO project, the event IDs for different events need to be defined per system. At least at this point of the DDE development, there is no list of event IDs defined for specific events. Thus, the event consumers and produces need to have a common list of event IDs used in the system. However, a unified list of event IDs need to be considered in the future development of the DDE in order to foster the usage of the DDE in different systems.

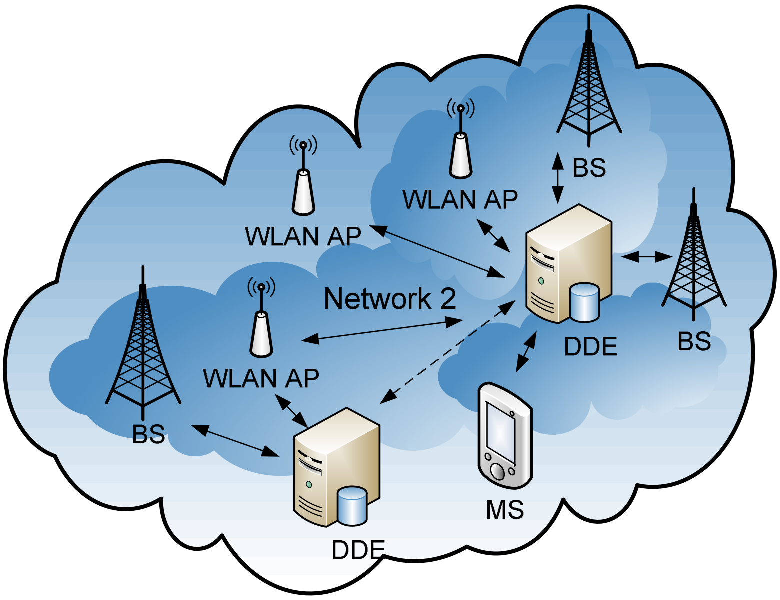

Figure 3 – DDE as an Access Network Signalling Enabler

2.2.1 Distributed Decision Engine Message Exchange

The operational principles of DDE are introduced in D2.2. Basically, DDE has five main message types, namely Registration, UnRegistration, Subscription, UnSubscription, and Event message, illustrated in the example message flow in Figure 4. In addition to these main messages detailed in the following subsections, the DDE supports Policy messages. Event distribution can be limited via access policies. All these messages apply also to the inter-domain signalling presented in Section 2.3.

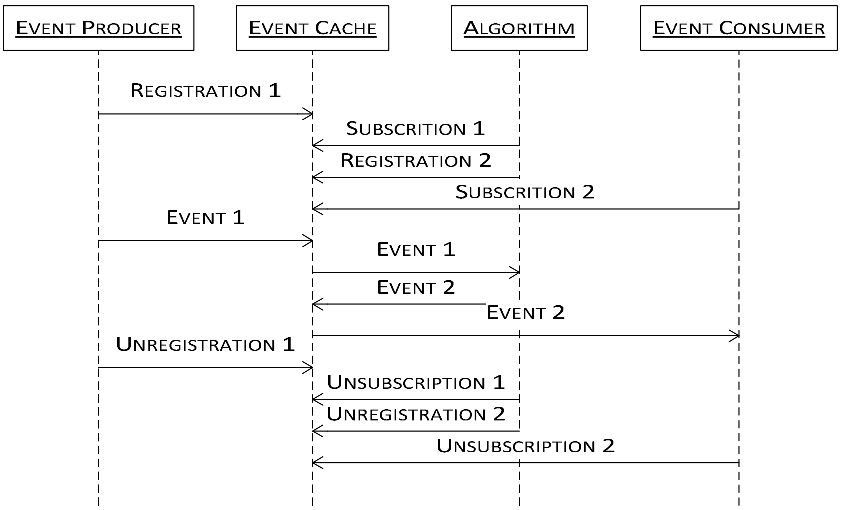

Figure 4 – An example of DDE framework message flow

2.2.1.1 Event message

Event message carries the actual information distributed by the DDE. Before a Producer is able to send events to the Event Cache, it has to register itself with a Registration message. The Event message has following fields:

- **Message Type (integer):** for Event messages type is always '0'.
- **Producer ID (string):** public key of the Producer

- **Event ID (integer):** value depends on the DDE message specification for the particular case.
- **Event Type (integer): v**alue depends on the DDE message specification for the particular case.
- **Time-to-Live (integer):** time, in seconds, after which event is interpreted as expired.
- **Payload Length (integer):** number of opaque data elements carried in the payload field’s list.
- **Payload:** a list of opaque data elements, the information to be distributed itself is stored into opaque elements of this list.
- **Digital Signature (string):** has three subfields separated with ‘:’. The first one specifies used digital signature algorithm, the middle one used hash algorithm and the last the signature itself.

2.2.1.2 Registration/UnRegistration messages

Before Producer is able to send events to the Event Cache, it has to send a Registration message. Respectively, when leaving the system, the Producer has to announce it to the Event Cache by sending an UnRegistration message. The registration messages include the following fields

- **Message Type (integer):** for Registration messages type is always ‘1’ and for UnRegistration message ‘2’.
- **Producer ID (string):** public key of the Producer
- **Producer Name (string):** llustrative and human readable name for the Producer for, e.g. visualisation purposes
- **Event ID (integer):** a value depends on the DDE message specification for the particular case
- **Event Name (string):** illustrative and human readable name of the Event for, e.g. visualisation purposes

2.2.1.3 Subscription/UnSubscription messages

Consumer can subscribe events with a Subscription message from the Event Cache and, respectively unsubscribe with an Unsubscription message. After a Subscription message, the consumer has to be ready to receive incoming Event messages.

- **Message Type (integer):** for Subscription messages type is always ‘3’ and for UnSubscription message ‘4’.
- **Consumer ID (string):** public key of the Consumer
- **Consumer Name (string):** illustrative and human readable name of the Consumer for, e.g. visualisation purposes
- **Consumer Address (string):** address-port pair from which Consumer can be reached by the Event Cache (receiving events).
- **Event ID (integer):** value depends on the DDE message specification for the particular case
- **Type Filter (string):** Consumer can set limitations to Events of interest. A value depends on DDE message specification for the particular case. With formatting:
    - ‘:’ your Consumer will get all Events with particular Event ID
    - ‘:int(x)’ all Events, which have the same Event ID and type equals or is less than x
    - ‘int(x):’ all Events, which have the same Event ID and type equals or is more than x
    - ‘int(x):int(y)’ all Events, which have the same Event ID and type between x and y (or same than them)
    - ‘:int(x):’ all Events, which have the same Event ID and type equals to x.
- **Producer Filter (string):** Consumer can specify Producer from which wants events by giving Producer IDs of interest
- **Digital Signature (string):** has three subfields separated with ‘:’. The first one specifies used digital signature algorithm, the middle one used hash algorithm and the last the signature itself.

2.2.1.4 Redirect message

This message is not defined as part of original DDE, but is defined to better support the DDE in an inter-domain scope, presented in the next subsection. If the subscription message from a resource event consumer refers to a resource information generated by a resource producer in a domain different from the one the resource consumer belongs to, a Redirect message is send back to the requesting consumer. In this way, it can subscribe to the correct and closest AG/DDE that manages the resource information of interest. Such a message has the following fields:

- **Message Type (integer):** for Redirect messages type is always ‘11’
- **Producer ID (string):** public key of the Producer in PEM format (Privacy Enhanced Mail) without newlines, and the first and the last line of the file removed (in practice, it contains only the public key itself). Public key (and Producer ID as well) is created at the producer start-up phase and is stored in .public_key.txt (or if the file exist, then it is read from there at start-up).
- **Producer Name (string):** illustrative and human readable name for the Producer. Used, for example, in visualization.

- **Anycast IP Address of the relevant BG/DDE (string):** hexadecimal format of the IPv6 address of the closest BG/DDE that can provide the resource information of interest.
- **Event ID (integer):** the value depends on the DDE message specification for the particular case. It is the same as used in the Event messages to be sent.
- **Event Name (string):** illustrative and human readable name of the Event. Used, for example, in visualization.

2.3 Inter-domain Resource Information Signalling

The previous solution focuses on the access network part. However, the CONCERTO architecture includes extensions to address a more general solution, which is able to manage cross-layer signalling generated and to be transmitted over the global Internet. This can be seen as a federation of domains, where the concept of domain can be associated with geographical, administrative or other aspects, as considered as most relevant by the network designers and administrators. For example, a domain could include a few access networks, a set of access networks and a core network, depending on the specific case. Regarding CONCERTO's use-cases, a single domain (including a transit-core network and some wired or wireless access networks at both the emergency area and the hospital premises) can be considered.

In order to extend the aforementioned solution in scope and coverage, the specification for a more general cross-layer approach, provided in D2.2, is integrated with, and actually instantiated to include and rely on the DDE-based solution. The aim of this section is to present unique and general purpose architecture for an effective cross-layer signalling provisioning, which will be leveraged to support the project e-health applications and use-cases.

As already described in D2.2, in each domain there will be a given number of AGs, which should be located near the producer entities, for a quick collection of resource information, and the consumer entities, to quickly and efficiently provide the produced resource information. When an AG in a given domain receives an update message, it spreads that message to the other AGs in the domain, which can be quickly accessed by the consumer entities. A message can also contain simply reference information about resources in the other domains, as collected first by the BG of the given domain.

Each AG can have two different behaviours. If it has requested information available (this is the case for resource producer and consumer in the same domain) it provides the information to the requesting consumer entity. However, if it does not have that resource information, it redirects the consumer entities to the BG managing that update according to the reference information received by the BG of its domain (this is the case for resource producer and consumer in different domains). Actually, the principle is the same as in caching systems (e.g. Content Delivery Networks, CDNs), where the consumer(s) can access the needed piece of information by the closest cache-server, which is updated by the server that receives first the resource information. The federation of the Global Internet into domains and the use of reference information (i.e. in an aggregated form, as simply as the IP addresses belonging to the related domain) for resource information generated by producers in other domains supports scalability. Such architecture also helps in achieving reliability against failure of an AG, as better explained hereafter.

The communication with and between gateways can be optimized using IPv6 multicasting and anycasting, respectively. Indeed, a message can be delivered from an AG to the others in the domain by using multicasting (i.e. the pool of AGs of a given domain belong to the same multicast group); while, the closest AG can be accessed by the resource consumer and producer through IPv6 anycasting (i.e. the same anycast address is assigned to all AGs in a given domain). This has the inherent benefit of protecting the system from a failure of an AG. If an AG fails, once reached again a stable and consistent routing table state for anycast addresses in the domain, a new AG can be transparently accessed by the producer and consumer entities (always the closest one, given the new pool of AGs available in the domain). If anycasting is not yet available in the network, unicast addresses can be used instead. In this transitory scenario towards the Next-Generation Networks (NGNs), which should fully support both multicasting and anycasting, the unicast addresses of the AGs can be obtained by a specific server (i.e. Dynamic Host Configuration Protocol , DHCP, server), and each producer or consumer entities have to properly manage them for efficiency purposes.

Naturally, each domain have assigned and registered to Internet Assigned Numbers Authority (IANA) a well-known multicast address and anycast address, which can be used for the specific purposes of the described cross-layer signalling architecture. When requested information is not available in the domain where the interested consumer is located, the anycast address of the issued domain is employed to reach the BG of that domain in order to access the requested information. For this purpose, a BG is necessarily advertised by routing protocols as the closest AG in its domain for the other domains (see D2.2 for more information).

Each BG notifies the other domains about the resource information that is available in its domain (i.e. the related resource producers belong to this domain) using the anycast address of the other domains. For an improved scalability at the Internet level, a hierarchy of BGs could also be considered in order to limit the amount of reference data exchanged between the BGs (hence, transferred across the network) by a number of them (or newly introduced gateways) collecting from and providing to multiple BGs reference data. Reference data can be also exchanged instead of the related resource information, when the content of an already existing database can be of interest for a resource consumer (see also D2.2). For example, Traffic Engineering (TE) databases or Management Information Bases (MIBs) present in a domain could be profitably exploited to acquire resource information to be leveraged in optimization algorithms. This is for the sake of completeness, since the slowly time-variant or static information of interest for the different components concerned in CONCERTO's use-cases can be provided by NIS only.

It is important to point out that if the issued resource information is highly time-variant, a direct communication between the resource producer and consumer is foreseen in the proposed cross-layer signalling solution for efficiency purposes (i.e. it reduces delay and bandwidth consumption). Indeed, this avoids the caching and provisioning of (quite an amount) stale information across the network, through a middle-box as for the typical problem of inefficient triangular routing.

As already highlighted, in each domain, in practice there usually is more than one AG/DDE (one of them being the BG for the respective domain) in order to also assure the reliability of the cross-layer architecture. In general, the number and locations of the AGs (DDEs) are evaluated in a way, which considers how much information should be delivered to which and how many entities in the network.

2.3.1 Cross-layer signalling management

According to a classification on the related time-variant nature, the management of the resource information by the CONCERTO's cross-layer signalling architecture is as follows.

1) Highly time-variant information: a direct communication between the resource event producer and consumer(s) is applied, since the use of a middle-box would result in an increased delay, overhead and bandwidth consumption. The event producer can leverage multicasting or simply multiple unicast connections (i.e. when multicast is not supported or the number of consumers is small) or existing controlling/feedback mechanisms if applicable. As stated above, either existing controlling/feedback mechanisms or direct communication between the producer and consumer(s) is applied to this kind of information.
2) Medium time-variant information: the event consumer subscribes to the AG/DDE for the requested resource information, while the corresponding event producer has registered for that. In this case, the AG/DDE publishes only the last (processed/aggregated) updated information (since the time-variant nature is in the order of tens of milliseconds at most, the last received update message should contain the last generated one). A re-direction of the consumer subscription to the BG/DDE of the issued domain is applied, when the resource producer and consumer are in different domains. The communication from the resource event producer and consumer to the AG/DDE for registration/provisioning and subscription, respectively, uses anycasting. Indeed, the closest AG/DDE can be reached for either collecting or requesting resource information. The anycast address of the domain the resource producer belongs to is used for the subscription, registration and notification messages. While, the anycast address of the domain the consumer is employed only once, if the resource event consumer and producer are in different domains. As stated above, the event-based mechanism (DDE) will be applied to this kind of information.
3) Slowly time-variant or static information: each domain has a logically separated NIS, either located at the AG or at a separate server machine. DDE can also be used for delivering slowly time-variant information if information is not available via NIS. Anycasting will be used as in the case of medium time-variant information, also for publishing (possibly processed/aggregated) updates to other domains, if consumers in such domains have subscribed to it. Multicasting will be used as in the case of medium time-variant information, if NIS's content is replicated in all the AGs of the domain it is located in. As stated above, the query-based mechanism (NIS) will be applied to this kind of information when applicable.

As highlighted, the proposed solution for the cross-layer signalling operates the same way from a functional point of view, on the managed resource information to be collected and provided for optimization purposes, as leaving the interested parties to exchange with each other highly time-variant signalling being more efficient. Indeed, an objective of the project is to introduce new features in NGNs, at a low cost and with as much as possible backward compatibility.

As described above, AG/DDE needs to support various message types. Essentially, the former messages of a subscription/notification event-based communication model, with the addition of a re-direct message. Such a message is used when the requested resource information is generated by a producer in a different domain from the one the consumer(s) belong to. Besides, the Event ID, event type, producer ID, consumer ID, TTL, etc. fields (see the next sections of this chapter for details), the re-direct message also includes the (well-known) anycast address of the domain the resource event producer is located in. In a transitory period towards NGNs, the unicast address of the BG in the same domain the producer is located in can also be used instead. Actually, as explained later on in this section, the re-direct message could contain the unicast IP address of a dedicated agent related to an already existing external database's in order to leverage its content for cross-layer optimization purposes.

2.3.2 Cross-layer signalling use cases

In order to understand better how the AG/DDE-based architecture works, the possible different use-cases for the resource information management are separately described below.

It has to be pointed out that if the last received value for resource information is still relevant, and this can be likely the case for slowly time-variant or static one, when a subscription message for it is received, such a value is immediately sent to the consumer without waiting for an update. To keep the use-case descriptions simple, this is not explicitly said. For the same reason, the spreading of reference data, in an aggregated form, to the other domains about the resource information available in a domain by its BG is not further discussed. As already stated, the BG of a domain is in charge of this operation, as well as of the spreading of reference data about the resource information available in the other domains, received by the BGs of those domains, to the other AGs of its own domain.

2.3.2.1 Cross-layer information producer and consumer in different domains

In this use-case, the communication steps are the followings:

1) The producer sends a Registration message using anycasting by defining a given event ID for the events
2) The nearest AG/DDE of the domain where the producer is located in receives the message and stores the information related to the event ID, the producer ID and its IP address. This information is spread using multicasting to the other AG/DDEs in the same domain
3) The consumer accesses the nearest AG/DDE by using anycasting with the aim of subscribing to events with desired producer ID and event ID
4) The issued AG/DDE realizes that the producer of the requested event ID is not in its domain. Therefore, it sends a re-direct message to the consumer in which the anycast address of the AG/DDEs of the domain where the actual producer of this event is located in is specified
5) The consumer sends the subscription message to the nearest AG/DDE of the domain the producer is located in by using anycasting
6) The nearest AG/DDE in the domain where the producer is located in, which is the BG of that domain, receives the message and records the information related to the event ID, the consumer ID and its unicast IP address. This information is spread using multicasting to the other AG/DDEs in the same domain
7) When an update message related to the given producer ID and Event ID is generated by the producer, it is sent by using anycasting to the nearest AG/DDE of the producer. Such message is cached and, if needed, processed/aggregated according to the defined algorithms for the related type of resource information. Then, the (processed/aggregated) update message is spread using multicasting to the other AG/DDEs in the same domain, including the BG
8) The BG sends the update message to the interested consumer using its unicast IP address

It is worth to remind that in the case of failure of the BG, another AG of the same domain is promoted to the role of BG for its domain.

2.3.2.2 Resource information producer and consumer in the same domain

In this case, the communication steps are the followings:

1) The producer sends a Registration message by using anycasting specifying a given event ID
2) The producer's nearest AG/DDE of the domain where the producer is located in, receives the message and stores the information related to the event ID, the producer ID and its IP address. This information is spread using multicasting to the other AG/DDEs in the same domain
3) The consumer accesses the nearest AG/DDE by using anycasting with the aim of subscribing events with the producer ID and event ID of interest
4) The consumer's nearest AG/DDE in the domain where the consumer is located in receives the subscription message and stores the information related to the event ID, the consumer ID and its unicast IP address. This information is spread using multicasting to the other AG/DDEs in the same domain
5) When an update message related to the given producer ID and Event ID is generated by the producer, it is sent using anycasting to the producer's nearest AG/DDE. Such a message is cached and, if needed, processed/aggregated according to the defined algorithms for the related type of resource information. Then,

the (processed/aggregated) update message is spread using IP multicasting to the other AG/DDEs in the same domain, including the consumer nearest one

6) The consumer nearest AG/DDE sends the update message to the interested consumer using its unicast IP address

In case of failure of an AG/DDE, the producer or consumer nearest AG/DDE can change. At a given time, only one AG/DDE receives directly the messages generated by the producer, and only one AG/DDE is active in delivering the (processed/aggregated) update messages to the consumer (on the basis of the current entries in the routing tables, at a stable state).

2.3.2.3 Resource information already available from an external database

As already pointed out, when resource information is already available by a given database, i.e. other than the AG/DDE cache, such as MIB database accessed through Simple Network Management Protocol (SNMP), no replication of data into the AGs is necessarily required to address the efficiency and backward compatibility (though, being an option). In this case, the communication steps are the followings:

1) The dedicated agent of the external database sends a Registration message by using anycasting specifying event IDs and producer IDs in aggregated form of its available content
2) The external database's nearest AG/DDE of the domain where the external database is located in receives the message and stores the information about the event IDs and producer IDs in aggregated form, and the IP address of the external database's dedicated agent. This information is spread using multicasting to the other AG/DDEs in the same domain
3) The consumer accesses the nearest AG/DDE by using anycasting with the aim of subscribing to events with the interested producer ID and event ID (as available in the external database)
4) The issued AG/DDE realizes that the requested resource information is already available (and managed by) the existing external database. Therefore, it sends a re-direct message to the consumer in which the unicast IP address of the external database's dedicated agent is specified
5) The consumer sends the subscription message to the dedicated agent of the issued external database, using its unicast IP address
6) The dedicated agent receives the message and records the information related to the event ID, the consumer ID and its unicast IP address
7) When an update message related to the requested producer ID and Event ID is available at the external database, it is sent directly to the interested consumer using its unicast IP address

The mechanisms and communication flows about the management of the external database, also in relation to the exchange of the registration, subscription and update messages, are out of scope for the CONCERTO's cross-layer signalling architecture.

2.4 Network information service

Information services are cited as important services in the current standards facilitating heterogeneous networking. For example, IEEE 802.21 [6] and 3GPP specified Access Network Discovery Selection Function (ANDSF) [7] specify information services to provide mobile stations information about access network possibilities nearby them. Information elements comprise the location and capability information about networks and individual access points. Table 1 shows an example of information content for an IEEE 802.11 Wireless Local Area Network (WLAN) network with two access points. Each parameter is defined in the IEEE 802.21 standard [6]. The parameters cover a wide range of information and based on this information each access point can be located, their capabilities can be assessed (e.g. mobility support, bitrates, cost, assured QoS parameters) and the connection to an access point of the network can be configured prior to a handover.

In CONCERTO, the information services are studied to store, in addition to information elements defined by the standards, also the coverage areas of access points, introduced in [8]. The current spatial databases allow storing polygon geometries and the coverage areas are represented as polygons. This helps finding the BSs in range of the MSs more reliably as the current solutions comprise only the access point locations. Based on this information and the knowledge of the technology, it is difficult to know the practical operational ranges of different BSs. The MS can query for BSs covering its current location and also query for BSs that are near but whose coverage area does not reach the MSs location yet. This information can be used to better plan the future handovers and make more proactive mobility decisions.

Table 1 – Example Information Element Content of IEEE 802.21 Information Service

```
Example_Concerto_network:
  IE_NETWORK_TYPE: 19:1:IEEE80211ag
  IE_OPERATOR_ID: concerto:5
  IE_SERVICE_PROVIDER_ID: Concerto
  IE_COUNTRY_CODE: FI
  IE_NETWORK_ID: Example_network
  IE_NETWORK_AUX_ID: NULL
  IE_ROAMING_PARTNERS: concerto1;4
  IE_COST: 7:NULL:NULL
  IE_NETWORK_QOS: 2;1%10:2%15;1%25:2%30;1%50:2%60;1%2:2%3;1%1:2%2
  IE_NETWORK_DATA_RATE: 56000
  IE_NET_REGULAT_DOMAIN: FI:4
  IE_NET_FREQUENCY_BANDS: 2400000:5100000
  IE_NET_IP_CFG_METHODS: 1:1;10.10.10.4:NULL:NULL
  IE_NET_CAPABILITIES: 100000000
  IE_NET_SUPPORTED_LCP:0
  IE_NET_MOB_MGMT_PROT: 000000
  IE_NET_EMSERV_PROXY: 1;10.10.10.254
  IE_NET_IMS_PROXY_CSCF: NULL
  IE_NET_MOBILE_NETWORK: TRUE
  PoAs:
    PoA1:
      IE_POA_LINK_ADDR: 6;00:11:22:33:44:55
      IE_POA_LOCATION: FI:Linnanmaa,Oulu;NULL;NULL
      IE_POA_CHANNEL_RANGE: 2426000:2448000
      IE_POA_SYSTEM_INFO: 19:1;6;00:11:22:33:44:55
      IE_POA_IP_ADDRESS: 1;10.10.10.1
    PoA2:
      IE_POA_LINK_ADDR: 6;66:77:88:99:00:11
      IE_POA_LOCATION: FI:Linnanmaa,Oulu;NULL;NULL
      IE_POA_CHANNEL_RANGE: 2421000:2443000
      IE_POA_SYSTEM_INFO: 19;1;6;66:77:88:99:00:11
      IE_POA_IP_ADDRESS: 1;10.10.10.2
```

As the information in NIS is relatively static in nature, the information delivery is reasonable to be carried out through information queries, instead of a subscription based solution, for example, used by the DDE framework. As the information is relatively static, the frequency for the queries is not often high, but information is queried, for example, when an MS is observing problems in the current access and need additional information about the possible handover targets in range. The enquirers can also maintain their own database for the network information based on the previous queries. This allows reducing the number of information queries and promotes the enquiry based information delivery solution. Preferably the NIS is made available at the IP network level (Layer-3) but, for example, the IEEE 802.21 standard allows also Layer-2 access to be optionally implemented for information services.

Figure 5 illustrates the overall usage of information services. Each network can have its own NIS server to handle local queries within its respective operational domain, defined by, for example, a geographical region. However, a single NIS server can also handle queries from several operational domains of a single mobile network operator. An MS sends its current location to the NIS server along with the parameters it is willing to receive about networks nearby its location. The NIS replies to the MS with information about networks and access points it considers as interesting ones for the MS.

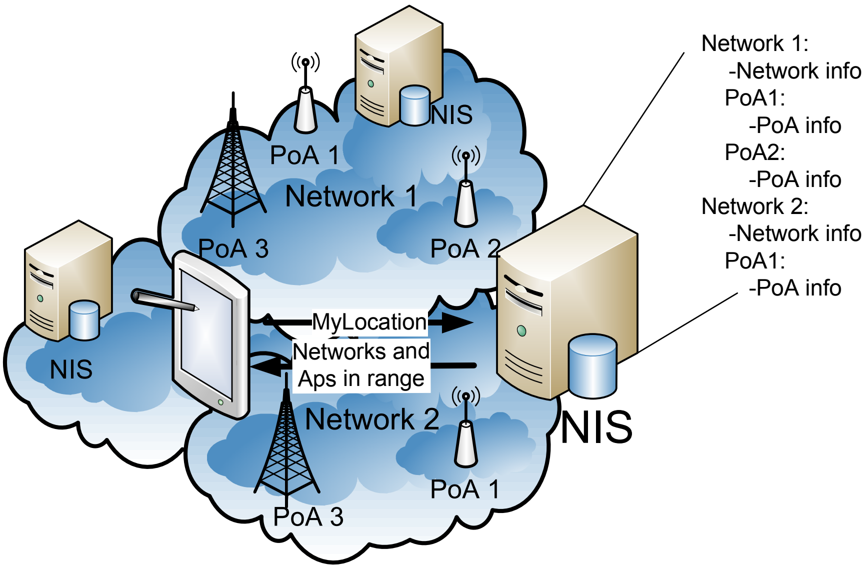

Figure 5 – Overview of Network Information Service

Figure 6 shows a possible NIS architecture. Mobile operators may divide their networks into regions for load balancing purposes, where each region has a NIS server handling information queries. If a mobile device moves from the area of the Region 1 NIS to the border of the area of the Region 2 NIS, the serving Region 1 NIS can forward the network queries to mobile operator's root NIS if it does not have timely information about the networks and access points within the area of the Region 2 NIS. If the root NIS does not have a consistent database of the information of each NIS, it can forward the query to the Region 2 NIS. If the mobile device moves to the Region 2, it can change its local NIS to be Region 2 NIS in order to avoid excessive query forwarding.

Mobile network operators (MNO) should collaborate in order to allow inter-MNO queries and to allow inter-MNO mobility. Thus, Figure 6 also shows inter-MNO queries through the root servers. This is particularly important as the better utilization of the existing network infrastructure becomes a more and more momentous factor. For example, limited radio spectrum already restricts sufficient network deployments to keep up with constantly increasing bandwidth demand. Roaming agreements are of crucial matter in this issue. However, for the emergency use considered in the CONCERTO project, the roaming issues could likely be solved more easily than for the commercial use.

In IEEE 802.21, the information service queries and responses can be encoded in Type-Length-Value (TLV) or the query in SPARQL Protocol and RDF Query Language (SPARQL) and the response in Resource Description Framework (RDF)/HTML. While the TLV encoding is more efficient with respect to the encoding processing and data transmitted [9], the latter option is more human understandable way to encode and transmit the data. In ANDSF, the message encoding is based on the Open Mobile Alliance (OMA) Device Management (DM) and uses the ANDSF Management Object (MO).

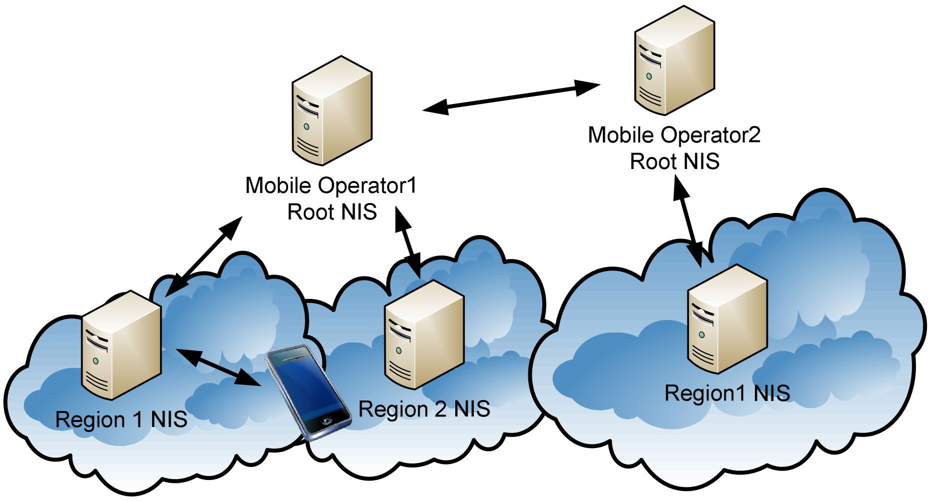

Figure 6 – NIS architecture

3 Use cases for cross-layer signalling architecture

3.1 Cross-layer information foreseen in different functionalities

Cross-layer signalling is either needed or could be beneficial for several functionalities included in CONCERTO architecture. In Table 2, different functionalities are introduced which need or could benefit from cross-layer information. The functionalities have been introduced earlier in Deliverable D2.2 and in this document we enhance the table by linking different information into the usage scenarios of CONCERTO defined in D2.1, and by adding time variance of cross-layer information and new functionalities which are recently identified. Time variance has been defined so that the variance of highly time-variant (HT) information is approximately in a range of 10-100 ms or less. HT information often considers PHY and MAC events and information exchange between layers inside one entity. Medium time-variant (MT) information is considered as a large range as most of the events considered in e.g. network video adaptation and network load optimization belong to this category. MT information can be perceived as information changing between 100 ms and a couple of minutes (e.g. less than 5 minutes). The changing frequency of slowly time-variant (ST) or static information is defined to be a few minutes (e.g. 5 min) and less frequently in our proposal.

Functionalities foreseen to use or benefit from cross-layer information are described in the table with the user/consumer and the source/producer of cross-layer information. The user or consumer can be defined as the system layer of OSI model which is using the available cross-layer information to make decisions during the transmission (e.g. whether to adapt the bitrate of the video to be transmitted, whether to prioritise the transmission of certain portions of the data stream). The source or producer of information is the system layer which creates this information based on measurements, observations, decisions etc. In addition to the user and source of information, the type of information is described in the table to give an example of what kind of information could be delivered within this functionality.

Table 2: Source and consumer of cross-layer information in different functionalities. (i) = in-band signalling

Functionality	**User of information**	**Source of information**	**Type of information and relevant attributes (e.g. size)**	**Time-variance and frequency estimate (HT, MT, ST)**	**Relevant use case(s)**
Reduction of network load by interactive view-switching	Application layer [end-user]	Network and Physical layers [access networks; LTE eNodeB, WiFi AP and transit network]	Available bandwidth, available networks (e.g. WLAN1, WLAN2, cellular…)	MT,1-10s ST, around 5 minutes (available networks)	1,2, 5,7
Adaptive HTTP streaming in cellular networks	Application layer [end-user]	Network and Physical layers [access networks; LTE eNodeB, WiFi AP and transit network]	Available bandwidth (also recent history), delay	MT, 1-10sat NET HT, micro to milliseconds at PHY	all
Adaptive camera set for FTV	Application layer [ambulance]	Network and Physical layers [access networks; LTE eNodeB, WiFi AP and transit network]	Available bandwidth (also recent history), delay	MT1-10s at NET HT, micro to milliseconds at PHY	1,2,5,7
Data fusion and ranking for multi-source transmission	Application layer [ECC]	Lower layers (MAC and physical) [Cameras & Medical Devices]	Source positioning information, camera orientation	MT, 100 ms – 1 s (for mobile devices) ST, several minutes (for stationary devices)	1,2
	Application layer [ECC]	Lower layers (MAC and PHY) [LTE eNodeB, WiFi AP]	Available rate, wireless link quality indicators (e.g. BER, PLR, delay, CQI, SNIR)	MT, 100ms – 1 s	
	Application layer [ECC]	Application layer [End-user application]	End-user preferences, quality feedback	MT, 1 – 10s	
	Application layer [ambulance]	Application layer [ECC]	Source ranking information, target source rate	MT, 1 – 10s	
Adaptation of frames and computation of FEC parameters	Application layer [all transmitters of multimedia content]	Lower layers (MAC and physical) [LTE eNodeB, WiFi AP]	Available rate at application layer, expected error/erase probability	HT and MT ms to 1s	all
Multipath streaming of medical video	Transport layer [all transmitters of multimedia content]	Application layer [all transmitters of multimedia content]	Layer information and/or priority	HT(i), milliseconds	1,2,4,5,7
Packet-level protection	Transport layer [All information sources]	Application layer [All information sources]	Source priority information	HT(i), milliseconds	all
MAC level scheduling for the down and uplink	Lower-layers (MAC and PHY) [LTE eNodeB, WiFi AP]	Application layer [Cameras & Medical Devices]	Source priority information	HT(i), micro to milliseconds	All use cases involving LTE/WLAN links

	Lower-layers (MAC and PHY) [LTE eNodeB]	Application layer [ECC]	Source ranking information, target source rate, target link quality (e.g. target BER, PLR, delay)	MT, 1 – 10s	
Service Differentiation in the network	IP- and lower layers [all network nodes]	Application layer [Network Manager-Operating Centre]	Settings for configuration, operating mode, allocation of resources, etc., consistently across multiple layers	MT, seconds ST, more than 10 minutes	All
Content-awareness in service differentiation at IP layer (based on media type and related constraints)	IP-layer [all network nodes, especially transit network]	Application layer [all transmitters of multimedia content]	Traffic type, layer information and/or Priority	HT(i), less than 10 milliseconds	All
Proportional service differentiation at a network node	IP-layer [Transit network node]	Lower layers [Access network at the receiver side, e.g. LTE eNodeB, WiFi AP]	Delays for each service class/queue	HT(i), micro to milliseconds	All
Consistent service differentiation across multiple layer at a network node	Lower layers [all network nodes, especially access network]	IP-layer [all network nodes, especially transit network]	Service class identification	HT(i), micro to milliseconds	All
Resource information collection	Application layer [AG/DDE]	Resource information producer	Medium and Static/ slowly time-variant status, configuration, etc. information	MT and ST, from tens of milliseconds to hours	All
Resource information retrieval	Resource information consumer	Application layer [AG/DDE]	Medium and Static/ slowly time-variant status, configuration, etc. information	MT and ST, from tens of milliseconds to hours	All
Handover optimisation	IP-layer [LTE eNodeB, WiFi AP]	Application, Network and physical layers [NIS and monitoring entities]	Available bandwidth, available networks (e.g. WLAN1, WLAN2, cellular…), available access points, available QoS guarantees, etc.	MT, seconds (quality events) ST, from hours to months (network information service events)	1,2,4,5,7

3.2 Cross-layer signalling in CONCERTO usage scenarios

Seven use cases have been identified by CONCERTO project as being potentially beneficiaries of telemedicine applications. Their full description, including usage models, technical and functional requirements and potential benefits, is presented in deliverable D2.1. The most important scenarios to be addressed by the CONCERTO simulator and demonstrator are defined in the deliverables D6.1 [3] and D6.2 [4]. In the following we will give an example how different cross-layer information can be utilised and how the proposed cross-layer signalling architecture is used to share this information. The main scenarios for ambulance and emergency areas (scenario 1) and emergency area with multiple casualties (scenario 2) are used as an example.

In the emergency area, it is important to find the adequate networking resources for the ambulance to transmit the required medical streams, adapt the streams to utilise the available resources efficiently, and to transmit all other additional information to the hospital for advice and preparations in the hospital. One of the main issues is to find an appropriate network and access point for the communication between the ambulance and the hospital. NIS helps ambulance find BSs in range and information about them to assess the best possible alternative. NIS resides in the network and the ambulance should have network connectivity before it can query NIS for other available alternatives. For example, the ambulance is likely connected by default to a BS of its primary mobile network operator's network. Figure 7 illustrates this scenario, where the blue polygons depict cell coverage areas stored in the NIS, as introduced in more details in Section 5.

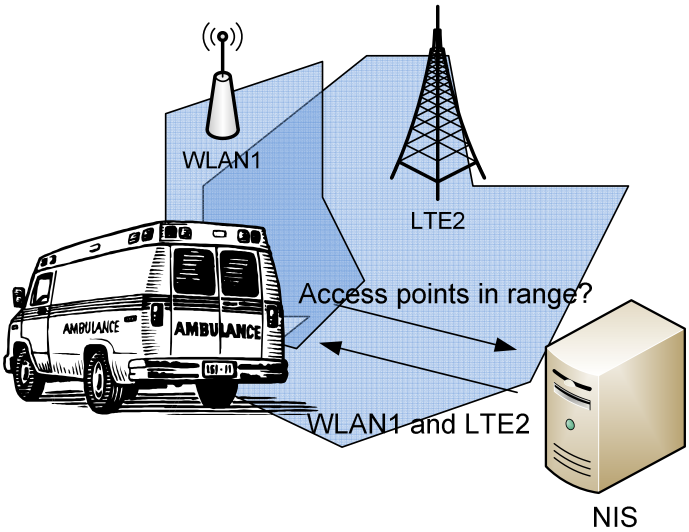

Figure 7 – NIS to provide information about access points in range

When the ambulance is moving towards the hospital, the NIS enables finding the access points of different mobile operators nearby without scanning through the whole radio spectrum. The coverage area information in the NIS allows the ambulance to choose the most potential access point candidates on the driving route beforehand and make, for example, necessary configuration in the access points to reserve adequate resources for having a guaranteed quality of service throughout the emergency situation. The ambulance sends its current location along with request for information elements it is willing to receive from the access points that can cover its current location. The NIS returns this information back to the mobility management entity in the ambulance.

Figure 8 illustrates a scenario where the ambulance transmits videos through the emergency coordination centre to the hospital. The video clients in the hospital side feedback the current quality indication to a single logical DDE of the coordination centre. As the ambulance may use several networks while on the move and the serving DDE may change, it is better to use only the DDE residing in the coordination centre side, which is known by the ambulance and the hospital's video client. The ambulance can use the same DDE for subscribing to the events regarding the video quality and the video client in the hospital sides knows that the DDE of its emergency coordination centre is used for the feedback signalling regardless of the location of the ambulance. The DDE remains the same, although the ambulance switches to another network.

Based on the feedback from the video client, the video sources in the ambulance can use the feedback information for adapting the bitrate of the stream(s). The video sources in the ambulance can also use the access network signalling, illustrated in Figure 3, to get timely information about the available capacity in the used BS and adapt the video streams accordingly. BSs registers an event related to the remaining capacity to their local DDE and feed the DDE with events. The ambulance subscribes to this event from the same DDE. When the DDE resides within the access network, it is easily reachable from both entities.

The same capacity event can be used to trigger the discovery of BSs in range. For example, the BS discovery can be initiated when the event indicates that the current access point is not capable of providing sufficient capacity or its service level is observed to be degrading and soon affect the attainable QoS level. The ambulance may have several networks in range. When the video quality in the currently used one becomes bad or the connection is otherwise considered as insufficient for the video based on the received quality indication events, the network can use the NIS services for finding other options before the quality drops to intolerable level, as discussed above.

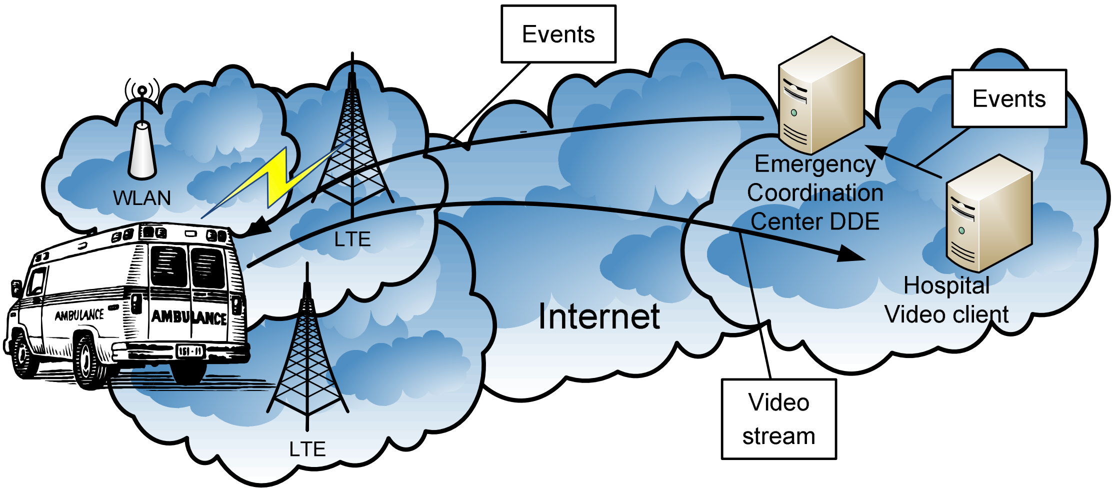

Figure 8 – DDE event reporting to indicate the received quality to the video transmitter

The ambulance or any other entity transmitting data to the emergency coordination centre side can monitor the current network and link condition as discussed above and illustrated in Figure 3. The inter-domain signalling can be used to find resources from other network domains, possibly operated by other mobile operators. For example, inter-domain DDE signalling can enable finding users nearby the ambulance to assist in the video transmission.

Figure 9 illustrates an overall scenario, where the ambulance uses two accesses for transmitting the video, over LTE and WLAN. These access points can be found from the NIS server directly. Moreover, the inter-domain DDE event delivery could be used to find resources in other domains/networks, for example, to find assisting accesses, such as mobile devices in proximity, which could act as a wireless relay to help in the video transmission. For this particular use, the DDE can have specific events defined for requesting and receiving resource information from the networks nearby for emergency use. The implementation of the DDE is done flexible in order to allow a wide range of cross-layer signalling usage scenarios. Thus, different event types and contents are not specified in details in the DDE specification, but there is adaptability to define use case specific events. For example, DDE enables defining an event for sharing resource information between entities in different network domains. For this, a resource request and resource information events need to be defined, as all DDE events for different systems. As discussed earlier, in the DDE, there is no pre-defined list of events and event IDs available for different systems.

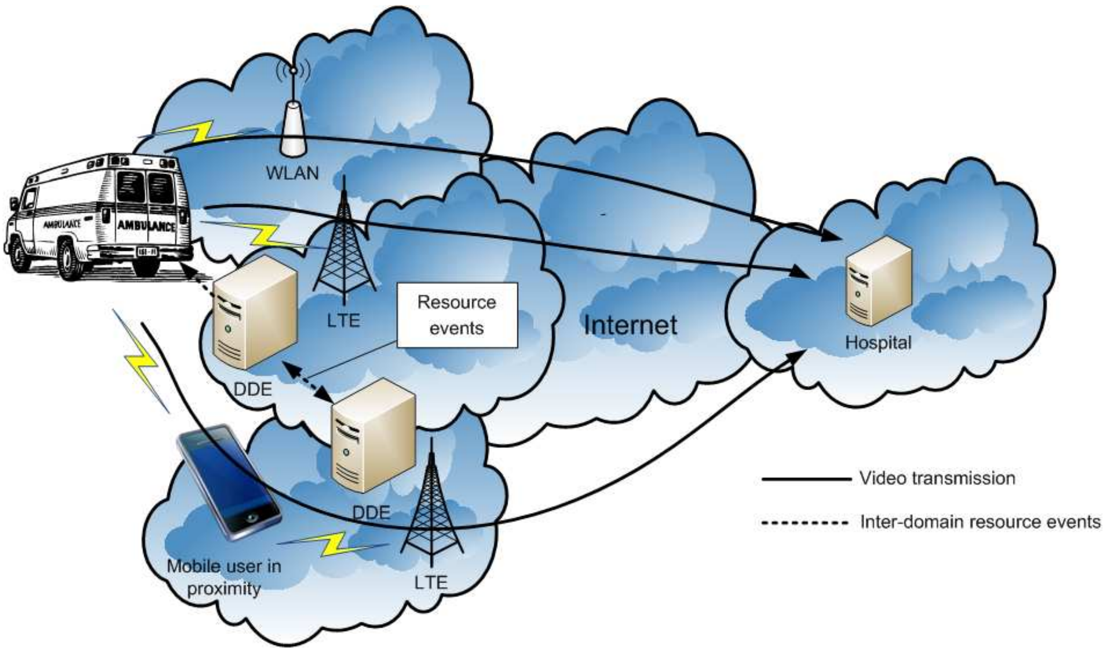

Figure 9 – Inter-domain resource events for finding assisting network access relays

The mobility management entity in the ambulance, taking care of, e.g. access point selection and service quality adaptation, can subscribe to resource information near its current location from its local/nearest DDE. In order to be able to do so, the ambulance first registers a resource request event and then sends an event containing its current location and a unique event ID for the resource information. Moreover, the ambulance needs to subscribe to resource information events. The network resource management entities (residing e.g. in AGs/DDEs), handling overall network resource sharing, have subscribed to resource request events and after that they will deliver this request to the resource management entities within the same domain and in the neighbouring domains. The entities that observe to have resources in the requested areas start sending events with the given event ID regarding resources near the location of the requesting entity. The resource management entities can use the DDE also for receiving resource information from the access points in its domain. Each access point sends to DDE events about its resources (e.g. current load, number of users, access point location and possibly also the coverage area), subscribed to by resource management entities. The locations of the ambulance and the resource points are essential in this signalling scenario.

When there are many casualties, the amount of traffic is most likely bigger due to several video streams and more data to be transmitted. In this case, more emphasis should be paid on the load balancing issues and to better utilise the existing network infrastructure in order to avoid a situation with insufficient network capacity for all video transmissions.

As described, cross-layer information and signalling architecture can be utilised in several ways to improve the reliability and efficiency of the transmission in these scenarios. The purpose of this section is to introduce the possibilities which the proposed cross-layer architecture enables. All possibilities are not implemented in the demonstrator and simulator, as in CONCERTO they are more focusing on proof-of-concept studies, but the cross-layer architecture is available in both to be used by those functionalities utilising cross-layer information which are implemented into the simulator and demonstrator.

4 Cross layer implementation in simulator and demonstrator

This section presents the implementations of the cross-layer signalling solutions to the CONCERTO simulation chain and the demonstrator. Overall, the cross-layer solutions are more extensively utilised in the demonstrator.

4.1 Simulator

The DDE is implemented in the simulation chain. The DDE server is deployed to the core network side of the simulation chain, as illustrated in Figure 10. In the simulation chain, the efficiency or scalability of the DDE are not measured but the DDE is used as a supporting functionality only, providing cross-layer information from any entities producing it and subscribing to it. Thus, the DDE implementation in the simulation chain is kept simple and the location in the middle of the transmission chain.

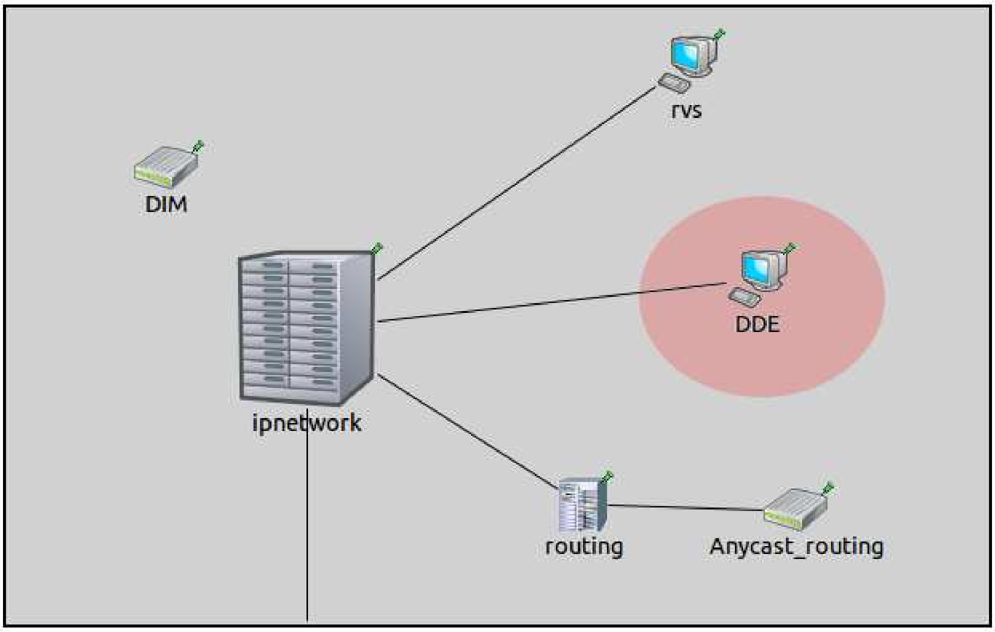

Figure 10 – DDE implementation in the simulation chain.

4.2 Demonstrator

In the demonstrator, both the DDE and a simple NIS implementation will be utilised in a cross-layer enhanced communication, as illustrated in Figure 11. A DDE server will be deployed to the network side, which can be accessed by all demonstration entities. A NIS server will also be running providing information about networks and their access points. The NIS will include coverage area database, which allows finding access points covering the MS's current location easily and fast.

An intelligent smartphone capable of doing inter-technology handovers implements a DDE client. It subscribes to events about the current network state (from BS). The events the BS provides are related to the data rate available in the cell. This information is utilized in intelligent handovers between a cellular network (e.g. 3G or LTE) and WLAN networks. Moreover, the smartphone can use the NIS for querying for access points within its range. This helps MS find alternative accesses for the currently employed one.

DDE client will also be deployed to the ambulance, which subscribes to DDE events from the ambulance video transmitter entity coordinating the video transmission. These events are used to optimise the video compression. The video transmitter uses the events received from the BS for transmission optimisation. All events are traveling through the DDE, although not depicted in the figure for clarity. See Figure 4 for an example message flow of the DDE.

More detailed demonstrator architecture has been provided in deliverable D6.2 [4] and will be refined in next WP6 deliverables. This section focuses only on cross-layer signalling architecture deployed in the demonstrator.

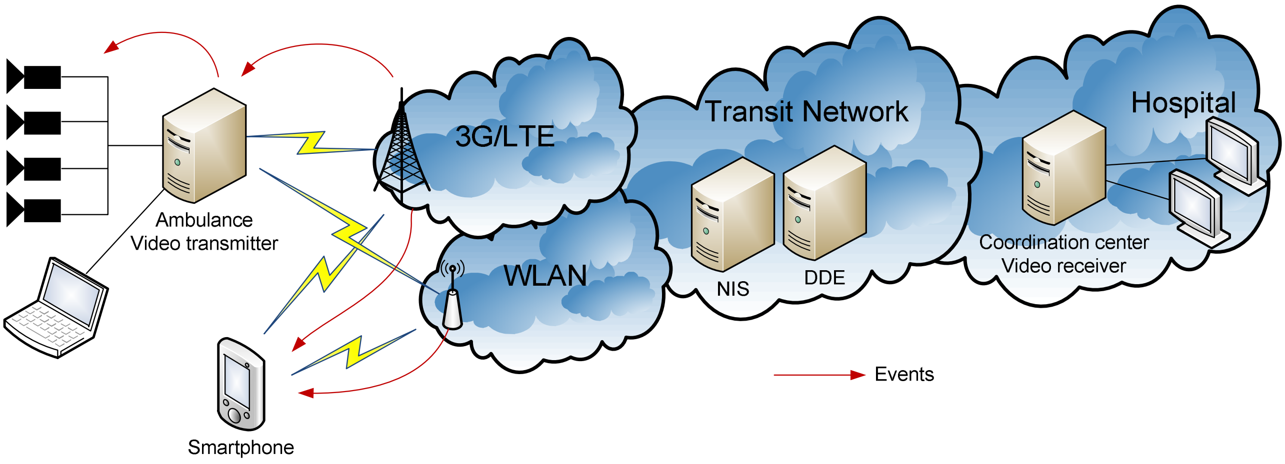

Figure 11– Cross-layer signalling in the demonstrator

5 Improving information service usability for cell selection

In the NIS of the CONCERTO solution, the information elements specified by IEEE 802.21 (similar information elements specified for the 3GPP ANDSF) are extended by an information element indicating the coverage area of the BS cells. The coverage areas can be represented as polygon geometry and stored to spatial databases and the information services are proposed to store also the information element about the coverage areas of each BS cell. However, as the NIS is not implemented in the simulation chain due to the lack of realistic model of cellular network including several BS with different coverage areas, this enhancement is simulated separately. The simulator used in the measurement reported below was implemented just for this purpose and no CONCERTO simulation chain was used. The simulator was implemented in Perl. The coverage area database and its possibilities for cell selection is studied in [8], where a PostgreSQL database with PostGIS extender is used in a study evaluating how coverage area information could be capitalized on in BS cell selection. Utilisation of information service for cell selection can improve especially the reliability of communication in emergency scenarios studied in CONCERTO project since it enables the selection of a cell efficiently so that communication between the ambulance and the hospital is secured.

In order to keep up with constantly increasing wireless capacity demand, the average cell size is anticipated to clearly decrease in the future network environment. Smaller cells such as IEEE 8021 hotspots, femto, micro and picocells better allow providing high capacity in their operational ranges. However, small cells also bring challenges for mobility management, especially, in high-speed vehicular mobility. While the small cells are ideal for stationary and pedestrian mobility usage, the vehicular mobility with small area cells would cause excessive handovers. The BS coverage area database would allow finding only big macrocells for the high-speed mobility. The mobile operators can direct the usage of smaller cells to low-speed mobility, for load balancing purposes.

The paper [8] shows simulation results for mobility scenarios with different distribution of femto, micro, pico and macrocells in a rectangular measurement area with side length of 10 kilometers. The found cells are first clustered into four clusters based on the cell area and the distance from the MS. The cluster including small cells and reside close to the MS are considered as pedestrian cells. The cluster whose centroid indicates large cells, but are relatively close to the MS are considered as vehicular cells. The cluster including also large cells, but whose centroid is further than the centroid of the selected vehicular cluster includes also interesting cells for high-speed mobility. However, if the travelled route is not known beforehand, the cluster with shorter distance was observed to provide better results.

The results are shown for two different cell distribution scenarios. Scenario 1 (S1) includes 15% femtocells, 35% picocells, 20 % microcells and 30% macrocells. Scenario 2 (S2) consists of more small cells, namely 30% femtocells, 30% picocells, 30% microcells, and 10 % macrocells. The polygons randomly located and stored in the database aim to realistically represent the practical coverage areas of the considered cells. The range varies from tens of meters with femto and picocells to 600-2000 meters with macrocells. The found cells are divided into pedestrian cells, vehicular cells and other cells, according to the criteria introduced above.

Figure 12 shows an average number of cells found within the range of an MS (1000 different random locations) with different number of cells deployed in the measurement area according to S1. With 500 and 1000 cells in the area, looking for a suitable cell size for the more detailed assessment of the handover target does not bring significant gain. However, with 2000 cells, when assessing only the cells considered as vehicular cells as handover target, the number of BSs to be considered is 17 cells less than going through all possible alternatives. Figure 13 shows the results in S2. As the number of macrocells is smaller, the number of cells found in different MS locations with the same total number of cells in the measurement area is smaller. However, significant gain can be attained for pedestrian and vehicular mobility if only the cells seen as most suitable ones based on the coverage area database is assessed as handover targets.

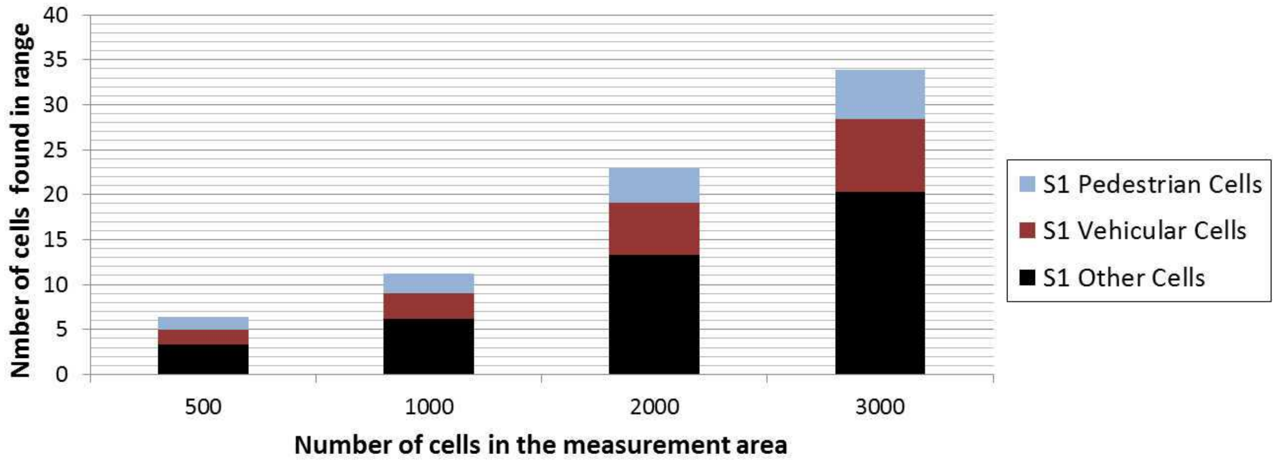

Figure 12 – Distribution of cells in range in S1

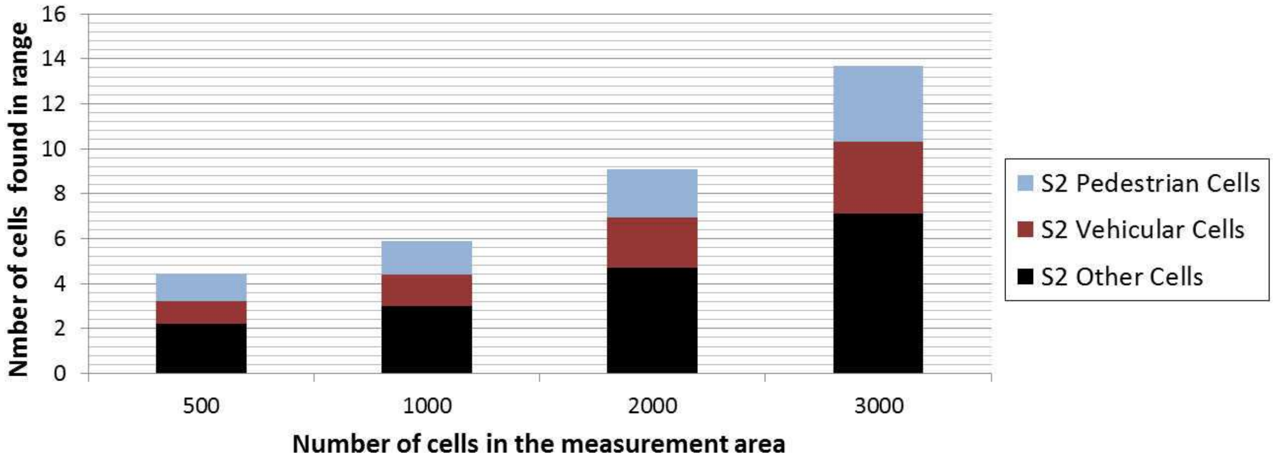

Figure 13 – Distribution of cells in range in S2

For more proactive mobility, the cells nearby the MS but those that do not cover the MS's current location are of interest as well. Figure 14 shows S2 results where cells whose coverage area border is at maximum 500 m away from the MS are factored in. In this case, the number of cells found increases and the clustering of cells to different mobility groups bring more advantage. For example, in S2, the proportion of vehicular cells found in different locations is only 17% of all cells found.

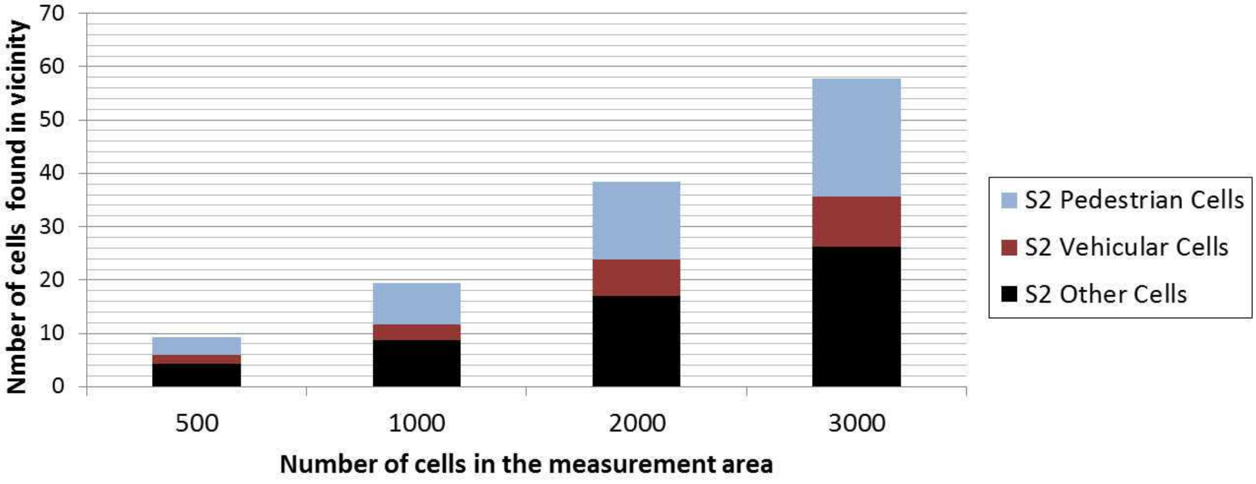

Figure 14– Distribution of cells in vicinity in S2

In Figure 15 the impact of selecting only the cells considered as vehicular cells on the number of handovers is shown for S1 and S2. The measurement area is travelled from left to right 100 times, each time with a different route, and the average number of handovers is shown in the figure. Overall, the more cells the measurement area includes the more gain with respect to the number of handovers can be attained with coverage area based cell selection. Moreover, the difference is the more pronounced the more small cells are deployed to the measurement area. For example, in S2 and with 2000 cells in the area, the number of handovers can be cut to half when the cell selection aims to affiliate with cells from the cell group considered as most potential ones.

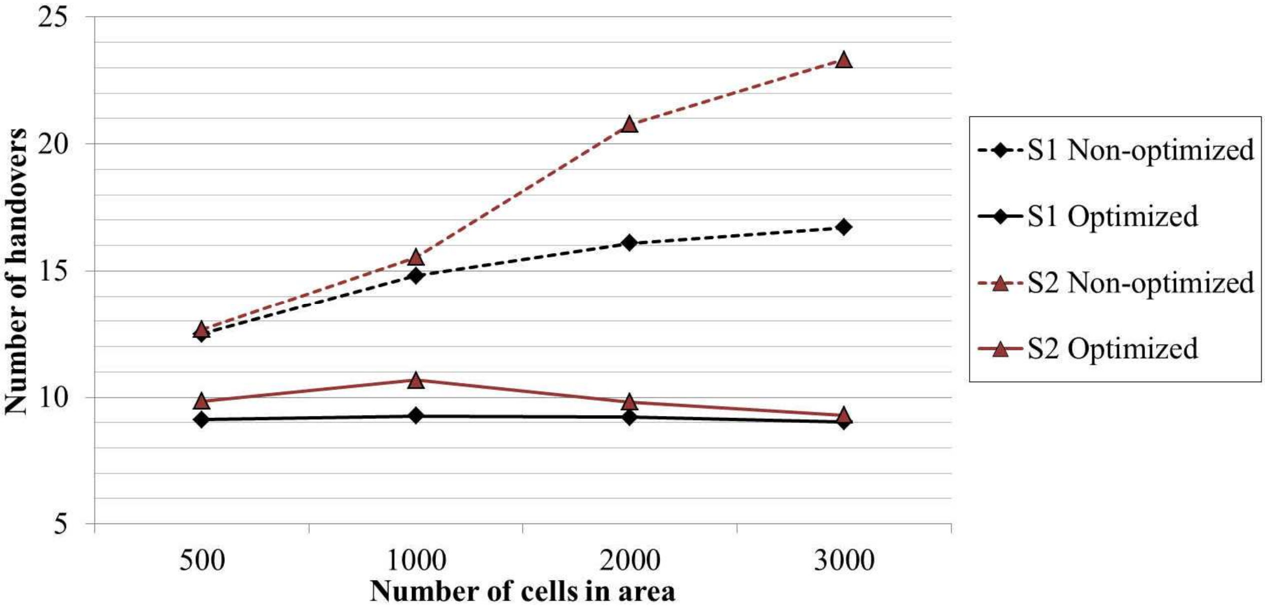

Figure 15 – Cell size improved mobility

The small cells, in addition to mobility challenges, substantially increase also the number of BSs. For optimized mobility, the BS candidates are assessed and when the number of BSs found in range and vicinity of the MS is high, the assessment becomes more difficult with respect to processing and decision time. The cell selection algorithm the results are based on randomly selects the handover target from the most potential cell group.

6 Conclusions

Cross-layer issues in future wireless networking are becoming more and more important. The optimization of networking from QoS and QoE perspective requires a variety of knowledge about states and conditions of different network entities. To deliver this information across remote entities require cross-layer signalling solutions. The solution for CONCERTO signalling architecture includes two parts (in addition to existing technology specific mechanisms); DDE and NIS. The usage of several mechanisms is based on time-variance of cross-layer information. Since different pieces of cross-layer information have different update frequencies, it is not efficient to use event-based mechanisms to all information. The CONCERTO signalling architecture provides a flexible event delivery solution through a registration-subscription mechanism, namely DDE. This solution can serve a variety of different cross-layer issues where different network entities can share both fast and slowly varying information with each other. However, delivery of very fast changing information, less than 100 ms, is not reasonable to be delivered over DDE. The events with this fast frequency are most often related to signalling inside a network entity or between a MAC/PHY of an MS and a BS. In these cases, technology specific feedback solutions are better to be used. In addition to the DDE, the CONCERTO solution introduces a NIS to reliably provide information about networks and BSs nearby the inquirer, especially, related to information that is static and/or slowly-varying. The NIS is enhanced with an information element related to BS coverage areas. The results shown in this document show the clear benefits of the knowledge of coverage areas in handover target cell selection. The number of handovers can be reduced even by half by favouring the use of large cells in high-speed mobility. Moreover, the mobile network operators can carry out load balancing through the usage of different size cells with different mobility scenarios. The proposed solution is available in both the simulator and demonstrator developed during the project with the relevant functionalities needed by the implementations.

7 References and glossary

7.1 References

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7.2 Glossary

3GPP	*3rd Generation Partnership Project*	*Standardization body specifying access technologies such as UMTS and LTE*
AG	*Access Gateway*	
ANDSF	*Access Network Discovery and Selection Function*	*3GPP specified solution for handling inter-access technology mobility*
BG	*Border Gateway*	*Gateway router connecting different network domains*
BS	*Base Station*	*Wireless access point*
CDN	*Content Delivery Network*	*System for content centric networking*
DDE	*Distributed Decision Engine*	*Cross-layer signalling framework*
DHCP	*Dynamic Host Configuration Protocol*	*Commonly used standard for automated IP address configuration*
DM	*Device Management*	*OMA specified device management protocol*
ECC	*Emergency Coordination Centre*	*Coordination centre entity*
HT	*Highly Time-variant*	*A metric for cross-layer information time variance*
HTML	*Hypertext Markup Language*	*Main mark-up language for creating web pages*
IANA	*Internet Assigned Numbers Authority*	*IANA controls numbers for network protocols*
IP	*Internet Protocol*	
IPv6	*Internet Protocol version 6*	
LTE	*Long Term Evolution*	*3GPP specified access technology widely referred as 4G*
MAC	*Medium Access Control*	
MIB	*Management Information Base*	*A database solution commonly used in SNMP*
MNO	*Mobile Network Operator*	
MO	*Management Object*	*Information objects or elements in the OMA DM*
MS	*Mobile Station*	
MT	*Medium Time-variant*	*A metric for cross-layer information time variance*
NET	*Network layer*	*Known also as an IP layer*
NIS	*Network Information Service*	*Information service providing information about networks and access points*
NGN	*Next-Generation Networks*	*A concept for future network systems and architectures*
OMA	*Open Mobile Alliance*	*OMA develops open standards for the mobile phone industry*
OSI	*Open Systems Interconnection*	*Reference Model for illustrating network protocol stack in seven layers*
PEM	*Privacy Enhanced Mail*	*An early standard for securing electronic mail*
PHY	*Physical Layer*	
QoE	*Quality of Experience*	

QoS	*Quality of Service*	
RDF	*Resource Description Framework*	*World Wide Web Consortium (W3C) specified model originally designed as a metadata data model*
SNMP	*Simple Network Management Protocol*	*Widely supported network management protocol*
SPARQL	*SPARQL Protocol and RDF Query Language*	*Query language for RDF language*
ST	*Slowly Time-variant*	*A metric for cross-layer information time variance*
TCP	*Transmission Control Protocol*	
TE	*Traffic Engineering*	
TLV	*Type-Length-Value*	*Data encoding method*
TRG	*Triggering Engine*	*Entity in the Triggering Framework cross-layer solution used in the FP7 OPTIMIX*
TTL	*Time-to-live*	
WLAN	*Wireless local area network*	*WiFi is a commercial name for a WLAN realization.*