On Ad Hoc Networks in the 4G Integration Process

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Abstract—The imminent combination of different wireless technologies will provide a very flexible and powerful platform to support requirements for future services and applications, which will be part of mobile communications beyond 3G. The main goal of this paper is to present the preliminary results of the ongoing research in the project ANWIRE (Academic Network on Wireless Internet Research in Europe) with respect to the system integration process for an envisioned environment of heterogeneous integrated networks. Specially, this paper is focused on the ad hoc network integration with fixed and wireless mobile networks in order to fulfill requirements imposed by mobile users with the expected “anytime, anywhere with anybody” type of communication. Besides the ad hoc networks introduction, the implications of ad hoc networks in the 4G integration process are also elaborated. The requirements for this integration are identified. A special focus thereby was put on the evolution of business models and their long sight to consider ad hoc related properties. Finally, a proposed Generic ANWIRE system and service Integration framework Architecture (GAIA) is described.

I. INTRODUCTION

Traditionally, the service provision in 2G networks, e.g. GSM, has been mainly based on voice services, closed business model support and limited operator differentiation due to a narrow set of offered services. Actually, mobile service provision is facing important advancements towards more flexible business models, with novel and dynamic Internet-like services, with the introduction of new 2.5G/3G generations of mobile communication systems, like GPRS, UMTS and CDMA2000.

Unfortunately, these 2.5/3G networks entail limitations to fulfill requirements imposed by current mobile users specially with the “anytime, anywhere with anybody” type of communication; among these requirements we can mention: terminal working effectively 'anytime, anywhere', service and interface personalization, ubiquitous communications, information and access, control of reconfiguration, cost, services, QoS and available networks, value-added multimedia services, access and download speed, mobility, security, location awareness, billing and interoperability [1].

In order to overcome these limitations, a traditional perspective in the industry was that an enhanced 4G network will evolve naturally from the 2G/3G with incremental improvements being brought about without any fundamental architecture changes. But, at the other hand, several complementary access technologies are evolving and emerging. In addition to 2G/3G networks, broadband WLAN type systems, such as IEEE 802.11a/b/g and Hiperlan/2 (H/2), and broadcast systems as DAB and DVB-T are becoming available. For ad hoc and short-range connectivity, systems like Bluetooth are being developed and several IP-based routing protocols are being proposed [2].

In the fixed access, systems like xDSL (e.g. ADSL) are increasing the user data rate significantly on the last mile. The imminent combination of these technologies represents a very flexible and powerful platform to support to support the above mentioned
requirements on services and applications, which will be part of mobile communications beyond 3G (3G+/4G). The expected results of such evolution are related to more flexible service provision (dynamic service registration and discovery, adaptable deployment and updating by providers) characterized by dynamic user registration, QoS support, flexible security schemes, flexible charging/accounting models, advanced profile management of users, networks and terminals; context aware, etc.

Therefore, from our point of view, 4G networks will be the result of the integration of the commented and future wireless network technologies, in order to ensure seamless handovers from one technology to another, thus providing a continuous and always best service (ABS) to always best connected (ABC) users anywhere, anytime, anyhow. The envisioned future imposes additional requirements as: support of terminal and personal mobility, usability on variable environments (high/low movement, indoor, etc) by terminal reconfigurability, ad hoc connectivity & networking, handover support and roaming to other different systems and networks. Among these technical requirements, ad hoc networking is increasingly important topic in wireless communications and has been regarded as one of the key features of 3G+ [3].

In this paper the preliminary results of the ongoing research in the project ANWIRE [4] is presented with respect to the system integration process for an envisioned environment of 4G. Specially, this paper is focused on ad hoc networks in the 4G integration process. Besides the ad hoc networks introduction, the implications of ad hoc networks in the integration process are also elaborated. The requirements for this integration are also identified. Finally, a classification of integration methods is presented and a proposed Generic ANWIRE system and service Integration framework Architecture (GAIA) is described in which ad hoc networks are involved.

II. ISOLATED AND INTEGRATED AD HOC NETWORKS

Ad hoc networks consist of a collection of mobile wireless nodes that dynamically create a network among them without using any infrastructure or administrative support, i.e., the necessary control and administration functions on such networks are only accomplished by the interactions among their constituent nodes. Due to these features, ad hoc networks are often described using other expressions like wireless multi-hop networks, self-organizing networks and mesh networks.

In such “isolated ad hoc networks”, mobile nodes could develop the role of an end terminal, also named mobile ad hoc host (MahH), which is the source or destination of data traffic flows and; mobile ad hoc router (MahR), which provides traffic relaying functionalities. The provision of connectivity among nodes can be difficult due to the error-prone nature of the wireless links, the unpredictability of the network topology and the limited power autonomy of each node. Even, more difficult could be the establishment of connections with stable QoS parameters which is challenging at different layers of the protocol stack and components of the terminal architecture [5].

Since 1970s, the research of ad hoc networking was mainly large scale networks for emergency/rescue and military purposes respectively for disaster and battlefield communication applications. Large scale isolated ad hoc networks are not suited to transport a large amount of data due to their very low traffic performance, slow topology convergence and security problems. However, these could be used to transport very urgent short messages (e.g. to inform about the location of an accident or to transmit tactical commands). Since 1990s, small isolated ad hoc networking has been experiencing a growing interest in the commercial and residential areas due the proliferation of small information computational devices and the emerging wireless technologies (IEEE 802.11, Bluetooth). This development is driven by the need to exchange digital information among people in direct contact enabled by ad hoc networking among a number or wireless nodes. Small Ad hoc networks seem to have commercial potential in business meeting places, hotspots, home environments and personal areas allowing fast exchange of documents during meetings, exchange of data when playing games in a group of users and connecting home appliance among other uses.

In the context of the heterogeneous and integrated 4G environment, ad hoc networking is considered an important solution to extend the radio coverage of wireless systems and multimedia Internet services to wireless environments [6],[7]. In these integrated ad hoc networks mobile ad hoc hosts and routers can gain
access to fixed networks through a specialized node which develops “gateway” functionalities; i.e. an additional role played by mobile ad hoc nodes could be as a mobile ad hoc gateway (MahG).

III. IMPLICATIONS OF AD HOC NETWORKS INTEGRATION

After the last section, we should note that a mobile node in ad hoc networks develops functionalities dealing with unplanned creation of a network infrastructure because MahH/R/G capable devices are owned and operated by individual users and not by a specific organization. In the context of 4G environments, these features make it difficult to implement ad hoc networks extensions of established fixed and mobile networks since it challenges the way in which technology traditionally is used.

A. Effect on service provision

Fixed and wireless communication networks have traditionally operated independently from each other. They developed deep vertical products, which tie the customer to a particular network. The concept of roaming between networks has only been offered to customers on a very limited basis. But in the Internet environment, telecom operators are not the main service providers; the collaboration of other companies for running complex or new services is required in this scenario.

The main goals of independent service providers in 4G environments are to feed the system with new and cheap services that once built to be used anywhere (via every air interface), anytime and by using any available terminal. ‘Anywhere’ and ‘anytime’ parts of the service access are easily supported by a wide deployment of variety of wireless access networks. Meanwhile terminal manufactures are continuously enlarging the list of devices the end user may use for accessing such services. This imposes extra cost if services have to be adapted to several different wireless access network technologies and different terminal types. The use of a single network technology, e.g. IP, and the use of a single development platform for services (e.g. Java and XML) will enable a fast and cheap roll out of services. Customization of services based on user terminal capabilities and the use of (e.g.) Resource Description Framework (RDF) for the definition of other service characteristics, connection properties, user’s profiles etc., will attach the complexity of the systems required for the provision of complex contents to users that demand personalized services.

In the case of ad hoc networks the problem of service is still more complex. In addition to service definition and deployment problems, delivery and discovery of services are also a concern (some services could be offered by the users in the ad hoc network). There is no any common management of the ad hoc network that may guaranty QoS for services with high requirements (e.g. VoIP, videoconference, application sharing, etc). A close collaboration between the application layer and the network layer has to be provided in order to allow a suitable support for such demanding services. For mobile user, accessing fixed network services the effect of ad hoc network extensions are likely to be felt in more frequent QoS violations and session renegotiations. In addition to the existing services offering, however, there are several new services aspects such as personal mobility. With ad hoc extensions users are more likely to use a range of terminals, from laptop PCs to low-functionality devices as well as a wider range of access technologies, users will want access to the same set of services, adapted to their location and the overall quality of the link whatever their location, terminal or access method is.

B. Effect on business model

Business models describe flows of money and goods between the actors involved in provision/use of goods and services.

1) Traditional business model of 2G networks.

The 2G value chain and business model is simply consisting of service providers and network providers. Service providers sell user terminals and billing packages provided by network operators who operate the networks. It was originally thought that service providers would offer billing and value added services but in practice they have been reduced to little more than outlets (stores); the billing, services provision and corporate functions have been firmly controlled by the operators. Since 2G content (voice and SMS messages) is all generated by the users themselves, the 2G value chain is effectively just about users buying handsets and billing packages from the operators through retail outlets. One of the reasons for this has been the 2G security system (in particular the SIM card) that was issued, authenticated and billed to by
network operators; therefore it might be argued that current 2G operators are acting as both network and service providers approximately (Fig. 1.a).

2) **Emerging business model in 3G**

With regard to service provision issues and market developments, existing 3G mobile telecommunication systems represent a paradigm change from the inflexible subscription-based offerings of their predecessor systems. Supported by a more flexibly regulatory framework, the emerging 3G mobile communications will be distinguished by the involvement of multiple players in the value chain, thereby enabling wide service offerings and permanent technological evolution. These new players will typically come in the form of high level providers such as content providers (CPs), application service providers (ASPs) and value added service providers (VASPs) that will contribute additional value to the overall service provision process (Fig. 1.b). For 3G networks it is often suggested that the value chain will get more sophisticated. For instance, the roles of suggested actors are as follows [8]:

- **Customers**: mobile users.
- **Retail Outlet**: buys wholesale airtime from the network operator to package and sell it on to retail customers. Retail outlets issue SIM cards and manage the billing relationship with their customers.
- **Access Network Provider (ANP)**: owns the spectrum and runs the network.
- **Mobile Virtual Network Operators (MVNO)**: own more infrastructure than ANPs in form of switching or routing capacity. They do not own spectrum or base-stations. MVNOs could also buy wholesale airtime from ANP and issue their own SIMs offering more services (e.g., using SIM application tool-kit for customizing the mobile terminal menu) [8].
- **Mobile Internet Service Providers (M-ISP)**: provide users with IP addresses and access to wider IP networks.
- **Portal Providers (PP)**: provide a “homepage” or “portal” for the access to a range of services that are in association with the portal provider.
- **Service Providers (SP)**: supply software products that are downloaded or used online.
- **Content Providers (CP)**: owners of music or web pages and so forth.
- **Payment Processing Provider**: The payment processing provider may either support individual products or wholesale payment processing to other companies, content providers or service providers.

In the recent years, telecommunication operators that have spent an important amount of capital worldwide in acquiring 3G licenses are expecting to recover these immense investments. The governments, which have benefited from these fees, are obligated to enforce political and administrative measures in order to make operators feel secure that they have invested in a profitable project. Ad hoc networks challenge this privilege, because they provide a free of charge and liberated means of mobile communication benefiting the users rather than the operators and service providers by having an impact on the earnings of operators. Some opinions appoint that the average revenue per user (ARPU), i.e. the income derived from the phone usage could drop to 0 Euro (excluding connections fees and the sale of user terminals) [9].

3) **Suggested business model for future 4G networks.**

As mentioned before, the integrated environment of 4G communication systems will include a variety of wireless access networks and service providers in a complementary manner. Over this heterogeneous infrastructure, different services and applications will have to be deployed in an efficient and flexible manner. On the other hand, mobile users will expect seamless global roaming across these different wireless access systems and ubiquitous access to personalized applications and content.

In the project ANWIRE [4] we think that more flexible business models will be a key enabler in facilitating system integration for a 4G wireless world (4GWW). However a fragmentation in wireless networking systems will result from an absence of a well thought out business foundation, which will provide the motivation for a real life integrated 4GWW. This business foundation will have to have a business attraction and not be something imposed. A key component of this foundation will probably also have to come from outside the major business players in the 2G/3G networks world if monopolistic features are to be contained. For example, if the underlying business model is to be founded on the necessity of mobile wireless users having an account with at least
one of the dominant network operators, it will always be difficult to escape the constraints and limitations effected by these operators for their own business reasons. It will also be very difficult business place for new network access entrants as the business agreements with dominant network operators (for interoperability, AAA, etc) will always be a critical component for their survival.

The still open question is what kind of business foundation is needed which will result in the evolution of a 4G communications environment with the attributes given above and be quite open to a wide range of new entrants (no matter what technologies they will introduce)? A second question also considered in ANWIRE is what kind of standardization and regulatory support it would require to come into existence? At the moment, two business foundation scenarios are addressed by ANWIRE with the following main actors [10]:

- **Mobile User (MU):** The consumer of available services which requests different types of services from different types of service providers by employing a communication and computing infrastructure of access network providers.
- **Access Network Provider (ANP):** provides access network infrastructure and transport medium. User Home Access Network Provider (UHANP) does this for its own mobile users and in so far as it does it for authenticated and authorized “foreign” MU currently in its coverage area but not registered with it (not having any account open with it), it is a FANP. An ANP could administer/manage several types of access networks and may also act as an Internet Service Provider (ISP) i.e. providing access to the Internet and (further through it) to xSP networks, to other ANPs networks, terminal reconfigurability, support networks etc.
- **Ordinary Service Provider (xSP):** This could be application SP (or developer) of user applications such as VoIP, teleconferencing, eCommerce, etc., mobile terminal re-configurability support, CP providing downloadable content (e.g. music files, MPEG movies, eBooks, etc).
- **Value-Added Service Provider (VASP):** Perform automatic registration and deployment of services provided by xSPs over the access networks. It can offer service adaptability and reconfigurability services, both for terminals and networks alike, within and in-between highly variable environments/domains by providing a mobile portal to the end user for personalized and context-aware service discovery and access.
- **Third-party AAA:** a clearinghouse-like entity, which provides authentication, authorization and accounting of both MU (wishing to use xSP’s services) and xSP (wishing to offer services over ANP networks).

A usual part of many xSP service management supports is the monitoring of service usage, the QoS it delivers in general and to individual MU, the connection/access network options available at anytime as well as the controlling parties of these options. A dynamic QoS management action could be to propose an alternate access network connection to the MU either because quality degrades or is likely to be degraded. Depending on the service, xSP policies, the MU type (home, foreign; gold, silver, bronze; etc.), the additional call costs caused by an access change will be handled by the MU or the xSP. In order to be able to offer better QoS to MUs, xSPs will probably need to form alliances with ANPs underpinned with service level agreements (SLAs), independent software vendors, platform vendors etc [11]. xSP may provide its services to MU directly or indirectly through Value-Added Service Provider (VASP).
In a first phase of business model deployment, all type of service providers (xSPs) could be able to offer their services through UHANP/FANP networks under respective business agreements with them [10]. In order to generate and submit just one itemized bill to the mobile user for all services used by him, one arrangement could be that the user pays only to his UHANP. The user is identified by a smart card inserted in the terminal currently used. A prior roaming agreement is established between FANP and UHANP so that UHANP on behalf of user pays the FANP for providing connection to services and invoices the user accordingly. Similarly business agreements will exist also between registered xSP (VASP, CP etc.) and ANPs where xSP may charge for the use of its services but user pays indirectly through her/his UHANP, regardless of whether the service is access through the MU’s UHANP or through a FANP.

In a second phase of business model deployment, xSP and ANPs will be able to offer their services to MU through the business agreements each and all will have with third-party AAA service provider. In this case the third-party AAA service provider becomes the central player, replacing the UHANP at its precedent privileged position in the business model. This will eliminate any barrier to new ANP into the wireless access network market. MUs will have agreements with one or more third-party AAA service provider, just as they have one or more credit cards, and similarly through this entity will receive periodic itemized bills for all services used. For this to operate an obvious implementation is for the user to be identified by a smart card (e.g. containing her/his credit card details, etc) inserted in the terminal currently used, with a suitable public key encryption system. In this way each service charge (e.g. to ANP or xSP) may be paid directly to a third-party AAA.

In these suggested business models for heterogeneous 4G networks, the inclusions of unplanned and unmanaged ad hoc networks for extending ANPs will require alternative means of payments necessary when removing the special position of the access networks operators, and incentive scheme for ad hoc nodes that are indirectly involved in communication processes when relaying packets for other nodes. The MahRs/Gs nodes should be compensated for usage of their resources. For instance, they could be considered as special xSP nodes and hence included in the 4G business model in Fig. 1.c.

**Fig. 2.** a) Classical TCP/IP architecture design, b) Vertical Tight Coupling Design, and c) adaptive cross-layer design

### C. Effect on Terminal Design and protocols

Ad Hoc networks also present implications on the end system architectural design. The strict protocol-layer separation that guided the protocol design and development in TCP/IP for the traditional fixed Internet has clear advantages. It minimizes the shared evolution of the adjacent layers, as well as simplifies the protocol design. However, it increases the amount of information interchanged among corresponding layers reducing the performance and bandwidth utilization in the emerging Mobile Internet (Fig. 2.a). At the IETF MANET WG [2], it was argued that the differences in resource constrains of ad hoc network and the Internet lead to the necessity of reducing the horizontal communication requirements of the protocols and the increasing some of the vertical communication requirements within the protocol stack. Re-designing the protocol stack with that *tight logical coupling* of layers permits upper-layer protocols to bind more closely with lower-layer protocols, allowing the removal of some of the inefficiencies of the traditional horizontal communications (Fig. 2.b). But this approach is partially unwelcome when interoperability with the existing network is desired. It can most likely increase the reconfiguration of the protocol stack in roaming nodes between mobile and wireless multi-hop ad hoc networks. Due to this constrain, the latter approach is commonly adopted in lower layers (e.g., link layers) where the extent of interoperability is limited.
Additional ideas derived from the QoS support analysis in ad hoc networks inspire the philosophy of an adaptive cross-layer design of mobile terminals [13] (Fig. 2.c). This design approach while providing adaptation and optimization coordinately across multiple layers of the protocol stack reduce the inflexibility and suboptimal performance of the current TCP/IP protocol stack in ad hoc networks. This approach proposes the introduction of MAC layer technologies which adapt to underlying link interferences conditions, bit priorities and delay constrains; adaptive routing protocols to the current link, network and traffic conditions; and a application layer or middleware with soft QoS support to deliver the highest possible application quality when adapting to the underlying network conditions, etc. Thus, each layer is involved in an integrated and hierarchical framework in which each one should compensate for variations at that layer based on the time scale of these variations, i.e. changes in PHY and MAC layers are in various orders faster than changes in transport and application layers, if it results in ineffectively, then information should be exchanged with the next upper layers to proceed with additional adaptive measures.

Despite the features presented by the adaptive cross-layer design for ad hoc nodes, again, interoperability concerns are present when the ad hoc node should be able to interact with different type of access networks. An alternative modular design approach is possible in which specific modules, middleware and interfaces are included to enhance the exchange of information between layers, their coordination for adaptation and QoS support allowing, at the same time, their independent development and interoperability [14]. This approach is both flexible and open, i.e., new components for QoS support, such as codecs and QoS Service Providers, may also be downloaded during runtime in order to enhance the system. Besides, it is able to interoperate with other current and future architectures when designed with existing protocol standards (subject to further developments). This alternative has been defined and partially implemented in some projects [7].

IV. REQUIREMENTS FOR AD HOC EXTENSION OF ACCESS NETWORKS

Isolated and integrated ad hoc networks are quite a challenging issue when trying to adopt implemented services already being used in the Internet. Ad hoc network nodes are usually untrusted elements and owned by individual people. These and other features make us face the difficult problem of internetworking between ad hoc and Internet. In the following subsections, some requirements for ad hoc network integration are exposed:

A. Unicast and Multicast Routing

Integration of ad hoc networks with mobile communication networks requires adaptation of routing mechanism in order to allow the exchange of traffic between both systems. For instance, the IP traffic generated in (or accessing) the ad hoc network could be encapsulated for transportation using a non–IP based ad hoc routing protocol. Therefore, the MahG must understand routing protocols of the fixed Internet on one side and ad hoc routing algorithms on the other. It should be possible to use those two different routing tables in the gateway node (MahG).

Multicast communications can help reducing dramatically the resource consumption when routing packets to multiple destinations, especially when audio and video traffics are delivered, which tend to operate at high data rates. Therefore, multicast protocols are very important where the parties share the same medium and there are scarce resources.

B. AAA, Charging and Security

The authentication, authorization and accounting (AAA) services offers the possibility to check if some entity is who it claims to be, to allow the usage of requested resources and auditing the use of these resources. There are many authentication mechanisms ranging from physical meetings to sophisticated cryptographic mechanisms. In 4G architecture with integrated ad hoc networks in which routers and terminals may be trusted or untrusted, an authentication mechanism is indispensable. Otherwise, such architecture would be very difficult to deploy in real life. The authentication service should be in some cases interoperable with those used in the Internet so that the terminal could attach to one or several ASPs using the same or different authentication mechanisms.

Charging is closely related to authentication. When we face this problem in ad hoc network extensions, the problem becomes even more difficult. Users of MahR/Gs can agree to route datagrams coming from other peoples to some of their neighbors but, what if there is no ad hoc neighbor, and mobile
nodes have to route these datagrams through the UMTS network? Do users will to pay for other users’ traffic? Probably, the operators can offer users some incentive for such collaboration. These and some other questions (e.g. where will the charging information be stored?) must be also taken into account.

Security aspects are also important in ad hoc integration scenarios. Each domain that the user interacts with to get to the fixed network must be authenticated (or treated as totally untrusted) necessitating the requirement of end-to-end (E2E) encryption. MUs will encounter services that might be locally generated (in the ad hoc network) and need a way of establishing the credentials of that service. New certificate authorities (with more dynamic timescales) will be required to enable these services.

C. Quality of Service

In environments where high data-rates and interactive applications are used, QoS becomes a very important topic to be supported by the network. Several ad hoc routing algorithms have been enhanced with QoS features [15]. Many of these enhancements are closely related to the algorithm itself causing interoperability to be very difficult to achieve. The main problem has to do with E2E QoS, which is very difficult to achieve specially in environments where the routers may be continuously moving and links may be going up and down all the time. Efficient QoS signaling and link break detection mechanisms are needed in order to achieve this goal.

The interaction between QoS and mobility is also another requirement to take into account. In single access networks (AN), a high or low coupling of these mechanisms could be implemented. The level of integration between different ANs is important in the level of seamless vertical handover achieved; a mapping between QoS classes from one access technology to another is needed. However, since all IP will be adopted in the multi-access networks, the mapping will inherently be provided from the IP based QoS framework to each network access technology.

A full support of mobile terminals with QoS requirements can be accomplished by a combination of the following strategies: QoS adaptability, scalability, QoS negotiation, intelligent traffic control co-operation between the applications and the network element.

When a mobile ad hoc node must perform a handoff between two different technologies, the QoS may be seriously degraded. In this case, a tight cooperation between the applications and the network layer may improve the user-perceived QoS, i.e. the application layer should be able to adapt to the network conditions [13].

D. Address and mobility management

In an isolated ad hoc network there is no need to change the node’s address because no route aggregation takes place (i.e. in ad hoc routing protocol, for the most part, the node’s address is not related with its location) and the routing tables only contain host-based routes. Although, in order to be able to communicate with Internet hosts, each MahN must configure an IP address with the prefix of a reachable access router (AR). With this location–dependent address, IP packets can be received from and sent to hosts in the Internet.

In complying with the ABC concept, MahN should be able to roam freely from one access network to another. As with classical mobile nodes, in order to be able to communicate with Internet hosts, MahHs should select a different AR through a MahG controlling the configuration of a new IP address with a new prefix. Therefore, active MahG announcements should be available in the ad hoc network. If multiple MahG provide access to the Internet simultaneously, a selection mechanism should be able to choose the most appropriate gateway based on metrics. If load balancing will be supported in the ad hoc network, then this requirement is not strict.

To support roaming of active MahN, mobility management protocol (e.g. as Mobile IP) will be also required. Depending on roaming constraints, macro or micro-mobility protocols [16] should be applied so that the mobile terminal does not need to change its address whenever a handover takes place to an ad hoc network. The point is that an efficient and secure address management procedure is needed in the integrated ad hoc part such that the handover can rely on this mechanism.

E. Service Discovery

In fixed networks, most of the services are placed in servers accessible through the Internet and the clients just have to connect to the server. These services are easily accessible and do not need to
announce themselves. However, in unmanaged ad hoc networks the mobile nodes may also offer services and they may not be accessible. In this case, it is desirable to have some mechanism allowing a mobile node to find some specific service. The service discovery mechanism should be powerful enough to allow not only for service discovery but also for controlling AAA functionalities.

The topic of service advertisement and discovery has been extensively researched in technologies such as Jini [17] and the Service Location Protocol [18]. Ongoing projects like DIANE [19] aim at developing and evaluating concepts that allow for an integrated, efficient, and effective use of resources in the form of services in ad hoc networks.

F. Multi-homing.

Heterogeneous 4G mobile communications, under ANWIRE perspective, is focused among others things on multi-homed terminals so that some ad hoc nodes within the ad hoc network may become gateways to wireless or fixed networks (i.e. using UMTS, WLAN, etc…). Thus terminals could have different network interfaces with different technologies and probably connected to different ANPs.

G. Other Requirements

In addition to the above mentioned requirements, the user should be able to reconfigure or establish policies to control the terminal’s behavior, for example, when the terminal is allowed to perform a handoff between different network technologies or specify a list of trusted terminals which can use a device as a MahR.

V. TYPES OF AD HOC NETWORK INTEGRATION IN 4G

The current related literature (e.g. [3], [6], [7] and others) describe how access network providers can integrate different types of ad-hoc networks (stationary and/or mobile) extending their access networks by blurring the edge of the network Infrastructure. Unfortunately, almost all the proposals are focused on the integration at IP level and only few proposals cover the general aspect of implementing a complete integrated framework providing required functionalities as security, billing, QoS support, etc [11]. During the discussion on 4G scenarios described in the project [10], we identify two principal ways in which ad hoc networking features could enrich the user experience of 4G systems.

One alternative relies on improvements of the network elements of the access network providers (ANPs) such as access routers (AR) and the other option depends on the mobile user terminal capabilities (which we denominate MahG) and it is more related with a user-centric point of view. These alternatives are shown in Fig. 3. A third alternative could be the combination of both.

A. Planned access network extensions

The extended network provider [11], also known as cellular ad hoc network [6], includes a special type of wireless access router (WAR) for wireless interconnection. This means that at least one of a WAR neighbors must be another WAR. WARs are typically owned and/or operated by legal entities or organizations, like universities or network operators; WARs also are mains-powered and portable but changing position only slowly or never. Among other requirements, zero-configuration, self-organization, multi-hop transmission, QoS support and ad hoc networking issues are of particular importance for WARs. The fast deployment of such extensions should provide a cost-effective solution less dangerous for users [20].

B. Unplanned access network extensions

The second option is the unplanned extension of an ANP infrastructure by means of mobile ad hoc gateways (MahG). The MahG is a functionality allowing unplanned, sporadic extensions of the network infrastructure by leveraging special features
of the devices owned and operated by individual users, on behalf of other users, who are not able to access the network infrastructure. In other words, an individual, who uses her/his device acting as a MahG, provides an extension of the access service of the access network provider to the end users. This user acts as auxiliary network provider \[11\]. A MahG is a special case of mobile ad hoc router (MahR) or node able not only to connect to a multiplicity of heterogeneous wireless networks, but also to enforce user profiles/policies for dynamic configuration of the routing process, with respect to third-party traffic. This aspect is of key importance, since MahG resources are typically limited and the access to the network infrastructure is usually subject to charge. To this extent, specific AAA and security support is of particular importance for MahGs.

C. Planned plus unplanned network extensions

A third option of ANP extension is the combination of both planned and unplanned ad hoc networks (Fig. 4). The extension of the ANP thereby most probably is realized by WARs that are wirelessly connected to the fixed infrastructure.

Though the planned network extension seems to resemble a static and thus non ad hoc installation, their mode of operation is purely ad hoc in such a sense that no central management is applied. If for example one of the WARs drops out, other WARs will overtake respective responsibilities. Basically, a WAR runs similar ad hoc protocols like MahG. The latter in turn connect associated MahH to WARs to allow for Internet access when there is no secure or direct association with the ANP or the MahH/R is out of the range of WARs. However, the unplanned ad hoc network extension not necessarily needs to connect via the WARs. Instead, they may also connect directly to the ANP (not shown in Fig. 4).

VI. ANWIRE PROPOSAL OF AD HOC NETWORKS INTEGRATION IN 4G

ANWIRE Project has addressed the 4G system integration issue and came up with a generic architecture described in \[10\]. The general architecture (GAIA) is illustrated in Fig. 5 according to the first model of business model deployment proposal (section III.B.3). The GAIA architecture is focused on “domains”. We define a domain as a set of network elements controlled by the same policy manager. The policy repository is a set of policies. A policy is one or a group of rules, where a rule is of that form: (If <condition> then <action>). In GAIA, five domains are proposed. These are mobile node, service provider, user home and foreign networks and terminal home network domains. Each domain is composed by a policy manager entity, a policy repository and a profile (TABLE 1).

We assume that the initial subscription of the mobile user takes place in the so-called user home network (the UHANP mentioned in III.B.3). All user related definitions and subscriptions (e.g. with respect to services) are administered here in a user profile. The terminals are also subscribed in the terminal reconfigurability networks where a terminal profile is maintained in order to propose a terminal configuration to a given user service (it corresponds to a special case of xSP in III.B.3). The mobile user will have access to several network access providers, which also maintain their network profile. These visited networks are named user foreign network (FANPs) and they can be any wired or wireless network access technology. An additional specialized VAS Manager (VASM) is proposed in order to coordinate the service provisioning, service adaptation and reconfiguration control and management in a flexible way between the ANP domains.

The main issues in GAIA with respect to unplanned ad hoc networks are: policies creation, distribution, storage and coherence; signaling protocol, routing protocol and gateway selections; ABC mechanism and profiles management among others.
One proposed solution is the deployment of smart cards that will carry the user profile and user access profile. The smart card will also carry the ABC Manager, and will store the policies. The ABC decision will be achieved and enforced at the terminal level. These smart cards will be issued by access network providers who wish to extend his access network to an ad hoc network. This network provider will be responsible of updating the policies deployed in the ad hoc network. Another solution is to leave the user be responsible of creating his policies and his ABC decision mechanism. The issue will be to define the service agreement between the ad hoc network and the access network. In the case of policies managed by the network operator, this is not an issue: the ad hoc network is considered as an extension of the access network.

A complete description illustrating a generic scenario of access network extension is presented in ongoing research of the ANWIRE (Academic Network on Wireless Internet Research in Europe) project. The focus hereby was put on the future role of ad hoc networks in the integration process of 4G networks. Starting with general ad hoc related issues, the implications of ad hoc networks in the 4G integration process have been elaborated. Special attention was put on effects on service provision and business models. Based on this, dedicated requirements have been derived and future associations of ad hoc networks to other 4G infrastructures of mobile communications by planned and unplanned network extensions have been presented. The paper also describes the policy-based Generic ANWIRE Integration Architecture (GAIA) for 4GWW where access network providers are extended by mean of unplanned ad hoc networks.

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**REFERENCES**


Environments With End-to-End User Perceived QoS - The BRAIN vision and the MIND approach


