Paper

Ubiquity of Client Access in Heterogeneous Access Environment

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Abstract—With popularization of mobile computing and diverse offer of mobile devices providing functionality comparable to personal computers, the necessity of providing network access for such users cannot be disputed. The requirement is further reinforced by emergence of general purpose mobile operating systems which provide their full functionality only with network connectivity available and popular XaaS (Everything as a Service) approach. In this situation and combined with the fact that most Internet-based services are able to function efficiently even in best effort environment, requirement of ubiquity of network access becomes one of the most important elements of today's computing environment. This paper presents a general overview of the the vast group of mechanisms and technologies utilized in modern attempts to efficiently provide ubiquity on network access in heterogeneous environment of today's access systems. It starts with division of users interested in ubiquitous network access into broad groups of common interest, complete with their basic requirements and access characteristics, followed by a survey of both already popular and new wireless technologies suitable to provide such access. Then a general discussion of most important challenges which must be addressed while attempting to fulfill the above goal is provided, addressing topics such as handover control and mobility management.

Keywords—handover, mesh networks, mobility, technological networks, ubiquitous access, wireless networks.

1. Introduction

Very high and still growing rapidly popularity of mobile end-user devices, along with their considerable robustness and functionality falling into range previously reserved only for personal computers, results in raising demand for means of easy network access for such devices [1]. Moreover, concepts such as XaaS (Everything as a Service) and architecture of popular operating systems designed for mobile devices make presence of such access still more critical for users, as its lack will result in significant available functionality reduction.

In this situation, network access ubiquity becomes one of the most important requirements for environments such as metropolitan areas, industrial installations or various personal and cargo transportation systems. Many new concepts, like Smart Cities, Smart Grids, assisted living or intelligent transportation systems, depend on its presence. One can argue, that currently the above requirement surpasses in its importance even the ability to maintain a high level of transmission quality.

Wireless network technologies play a crucial role as networks access technologies, as cable-based solutions tend to be of limited utility in case of easily portable or mobile devices. As a result, a number of popular wireless technologies emerged, staring with Personal Area Networks (i.e. as ZigBee), through highly popular Local Area Networks (for example: Wi-Fi installations) and ending with Wide or Regional Area Network installations (mainly 2G/3G/4G technologies). A high number of wireless systems, utilizing this assorted set of technologies, have been deployed by numerous operators in high demand areas, creating massively heterogeneous access network environment. Additionally, many supporting technologies were developed, i.e., broadband mesh networks (providing self-forming, highly resilient network structures and good radio coverage in varied environments) or cognitive radio solutions, allowing for much better efficiency in radio frequency resource utilization, by taking advantage of currently unused transmission channels owned by external systems – for example unused TV channels.

Unfortunately, this diverse set of access systems does not necessarily guarantee constant, uninterrupted network access. In fact, many additional functions should be provided to consolidate such a diverse collection of access systems (divided by both technological and organizational boundaries) and offer users an ubiquitous network access.

2. Ubiquitous Network Access Usage Groups and Requirements

The necessity of communication convergence and ubiquity of network access is driven by both "technology push" and "business pull" [2]. New devices, access technologies and protocols create wide range of possibilities which can be offered to a user. At the same time customer demand, lower entry barriers for infrastructure and service operators, new business opportunities lead to new installations development and new services resulting in further popularization of mobile computing technologies.

Users interested in ubiquitous network access can be roughly divided into three main groups: popular access, infrastructure systems and technological networks, special systems and environments.

The first, popular group of users is mainly interested in obtaining uninterrupted access to Internet resources. Such users require relatively low Quality of Service (QoS), but

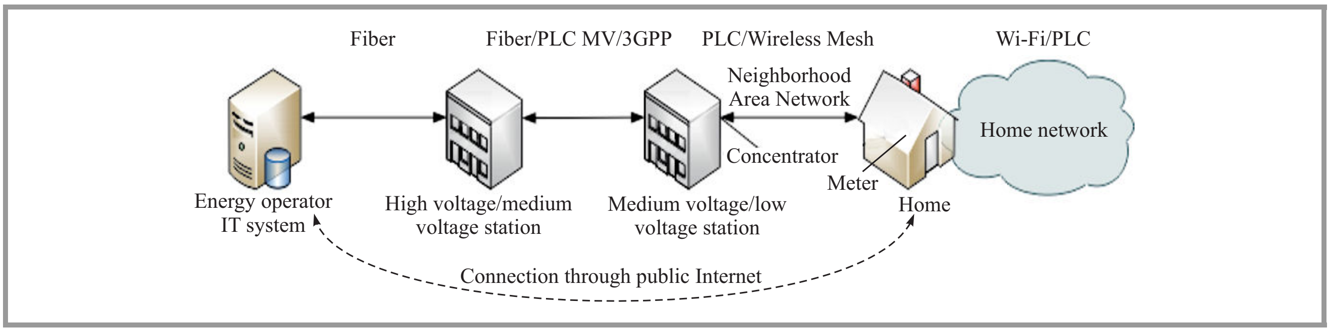

Fig. 1. Advanced Metering Infrastructure system as an example of technological network.

at the same time they are going to utilize wide variety of applications to different services access. Moreover, their subjective level of Quality of Experience (QoE) for a given QoS level depends not only on a requirements of a particular service they access, particular hardware and implementation they use, but also on their personal preferences and expectations. As such, providing very high QoS level (for example: hard QoS guarantees) is unnecessary, especially in case of Internet service implementations which are being developed for a network inherently lacking QoS guarantees.

At the same time, popular access systems need to correctly interface with a large and rapidly growing number of different client access devices. Fortunately, with emergence of universal, general purpose, mobile operating systems, obtaining software compatibility is much easier than in past years, when each hardware device utilized a dedicated firmware implementation.

From access system operator's view, popular user group consists of a potentially anonymous high number clients interested in obtaining access to a high number unspecified services, with comparatively low QoS requirements, from which throughput can be considered the most important. It is also worthy of mention, that in this user group, necessity of providing ubiquitous network access for mobile users can be considered both technologically simplest (due to low QoS requirements) and most rewarding, as not only many new Internet services are well prepared for handling connectivity parameters fluctuations frequent in mobile wireless environment, but mobility of users itself creates demand for new services – for example location aware solutions for navigation or micro-payments.

Infrastructure and technological networks can be considered an opposite end of the scale compared to popular users. They serve a well defined, closed user groups, interested in obtaining a highly reliable access to a strictly defined group of services. Specific QoS requirements can differ greatly, but they can always be precisely defined.

Energy distribution-related computer networks can serve as a good examples of technological networks. With such systems as smart grids [3], Supervisory Control and Data Acquisition (SCADA) [4], Distribution Automation (DA) and Advanced Metering Infrastructure (AMI) [5], energy-related systems are omnipresent in populated and technologically developed areas. Of course other examples of this type, such as: emergency communication systems, metropolitan transport control systems, bulk warehousing and transport support networks, building automation or Internet of Things deployments cannot be discounted.

As can be seen in Fig. 1, an example DS-AMI system is a complex deployment, consisting of data acquisition and processing center, which can be connected to energy transmission and distribution substations with a diverse set Wide Area Network (WAN) technologies. Taking into account that such stations are located over large geographical areas, creation of infrastructure can be a significant investment for even big companies, eased in some part by the fact that it can be co-located with energy distribution grid.

Elements of the communication network system located relatively close to end-users are created with use of different technologies. Neighborhood Area Network (NAR) responsible for providing data transmission capabilities between distribution stations and metering equipment at customer premises, most often utilize Power Line Communication (PLC) solutions [6], thus reusing already present power distribution installation, or Wireless Mesh Network (WMN), creating resilient, multihop, wireless communication system, which coverage area extends with each participating end-user device.

Such large communication networks, which, due to their very connection with power distribution grids are able to provide coverage in practically all technologically developed areas, can be a very well suited as means of providing infrastructure for ubiquitous network access solutions. At the same time, an opposite trend can also be observed – instead of creating such complex systems, expensive in both creation and maintenance, it becomes a popular solution to utilize already present communication infrastructure in place of described structure chosen elements. One of the most popular examples include use of public EDGE/UMTS operator data services in place of WAN infrastructure. There is also high interest in idea of utilizing an already existing, general purpose Internet access present at customer premises for creating direct link between metering equipment and central data acquisition center.

From the above example, it is evident that technological networks can be seen as both efficient provider and highly interested client of ubiquitous network access solutions. However, regardless of the choice between these two

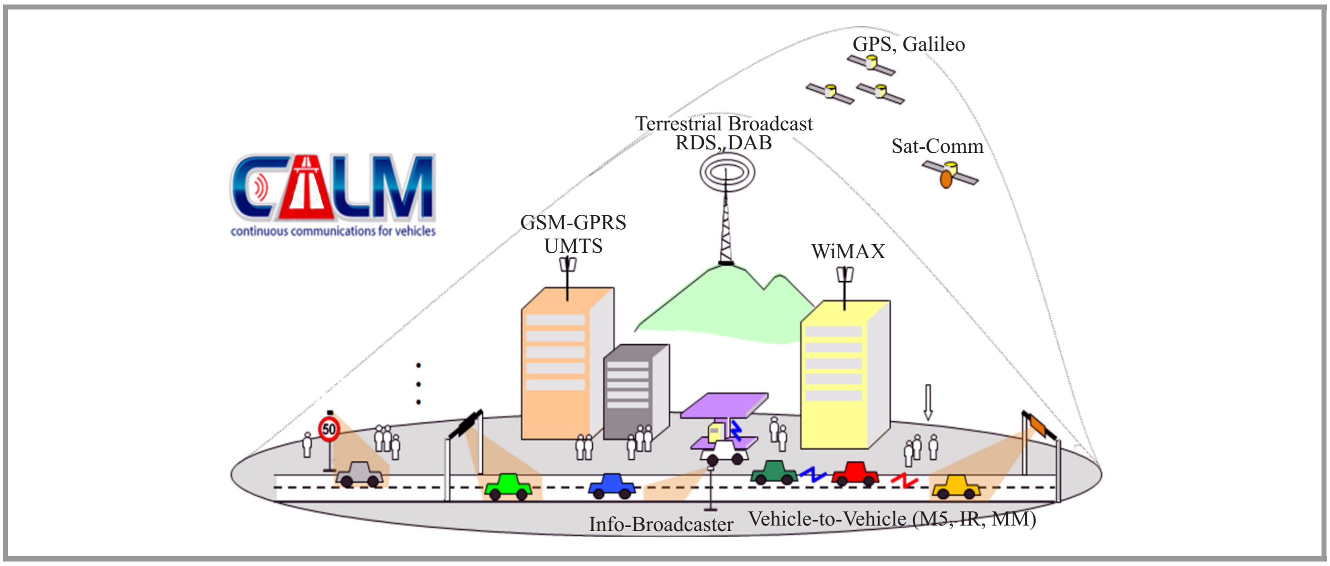

Fig. 2. Continuous Air Interface for Long and Medium distance usage scenarios.

possibilities made by particular energy companies, there are two emerging characteristics of such networks, which can be observed universally: move towards open standards and widespread employment of IPv6 communication. They both stand in contrast to earlier technological network deployments, which tended to utilize specialized, proprietary solutions, often compatible only with products of the same manufacturer. Development of mature open standards, able to provide necessary level of both functionality and reliability, combined with falling costs of industrial automation hardware capable of supporting IP-based communications make this evolution direction the most attractive one.

Another important example of specialized infrastructure solutions are vehicular networks. In their case both some requirements of popular access and some requirements specific for technological networks have to be addressed. A large user group utilizing diverse range of hardware solutions have to be supported, but, at the same time specifications for these devices being strictly followed could be counted on, due to legal requirements concerning devices allowed to integrate with vehicle systems. Moreover, apart from communication protocols and procedures, also services for this environment tend to be clearly defined, which leads to higher predictability of required QoS level. Many of these services, on the other hand, can have considerably higher QoS requirements then general Internet ones – especially in case of safety-related, automated solutions, i.e. collision avoidance mechanisms.

Continuous Air interface for Long and Medium distance (CALM) [6] can serve as an example of standardized solution for vehicular environment. The standard defines comprehensive set of elements necessary for creating a fully functional system, covering:

- a diverse set of access technologies, starting with wired access, and including wide range of wireless technologies such as IrDA, Personal Area Networks (PANs), short range RF broadcasts, Wireless Local and Metropolitan Area Networks (WLANs and WMANs) and cellular technologies (2G/3G);
- network layer mechanisms and protocols for handling communication within complex network structures – based on IPv6 protocol stack;
- network and service convergence solutions, allowing seamless integration with external network systems (including IPv4/IPv6 Internet) and both CALM-aware and proprietary services;
- application implementation and integration, for creating application level service providers and clients able to both seamlessly function in CALM network environment and take advantage of its additional functions, i.e. as user's location awareness;
- management and control mechanisms for all defined layers.

Two additional characteristics of this standard require a special attention in general context of ubiquitous network access. The first observation is based on the following list of communication scenarios which are supported in CALM environment: Vehicle to Infrastructure (V2I) Non-IPv6, Vehicle to Vehicle (V2V) Non-IPv6, V2V and V2I Local IPv6, V2I Mobile IPv6 (MIPv6) and Network Mobility (NEMO) (see Fig. 2) [7]. Non-IPv6 scenarios are included sorely for purposes of compatibility with existing proprietary solutions. The remaining scenarios clearly divide communication into direct interactions between 2 system elements (both V2I and V2V) – where basic IPv6 mechanisms are used for sake of simplicity and performance and universal, general purpose IPv6 communication mode. The observation particularly interesting from author perspective is that in case of general purpose communication, the use of network layer mobility management solutions, in this case

Mobile IP (MIPv6) [8] and Network Mobility (NEMO) [9] is mandatory. That clearly indicates the importance of this group of network mechanisms in complex heterogeneous access system environment.

The second observation is that despite high level of independence between services and access technologies used by client, the system allows services to utilize specific characteristics of a particular access technology to provide additional functionality. For example, low range transmission technologies can be used to broadcast warning messages over limited areas without need for inclusion of higher layer range control solutions.

Information about current user location proves to be very useful in providing services to mobile users. With currently available mobile devices being comparable to popular stationary computers in terms of their performance characteristics, one of their main limitations seems to be the user interface – required to be easily usable on small displays and with user input methods severely limited in their range and precision. With such constraints, mobile user's ability to efficiently absorb and filter large amounts of information by use of such an interface is strictly limited, so steps should be taken to further prepare information provided to him, taking into account his personal preferences and current needs. For this task, information about user's whereabouts can be of high value – for example: user entering public transport vehicle will probably be interested in ability to make necessary payments for a very specific line, tariff etc. instead of obtaining full and comprehensive information about a city's public transport system.

With precise geolocalization being both well researched and still difficult task, at Gdańsk University of Technology scientists have been researching the use of context localization – obtaining information about user proximity to various access network infrastructure elements. There is a high number of frequent tasks where precise geolocalization is both an error prone and not particularly efficient method, while context localization proves to be both easy and well suitable. For example, in already mentioned public transport example, is proves very difficult to clearly state if the user is on board of a given vehicle (Fig. 3) – due to both localization errors (with required precision being rather high) and unpredictable vehicle mobility.

At the same time, by a simple measurement of signal strength from on-board wireless access point, the above task can be easily fulfilled.

While the two broad user groups mentioned above cover a vast majority of ubiquitous network access users, there are also some specific environments and uses, where providing ubiquity of network access requires dedicated approach. As an example for such environment the author chosen a broadband maritime networking.

There is currently a number of systems and technologies used to provide digital communication between maritime vessels themselves and between them and shore infrastructure. However, due to their changing locations, unpredictable propagation characteristics, long communication

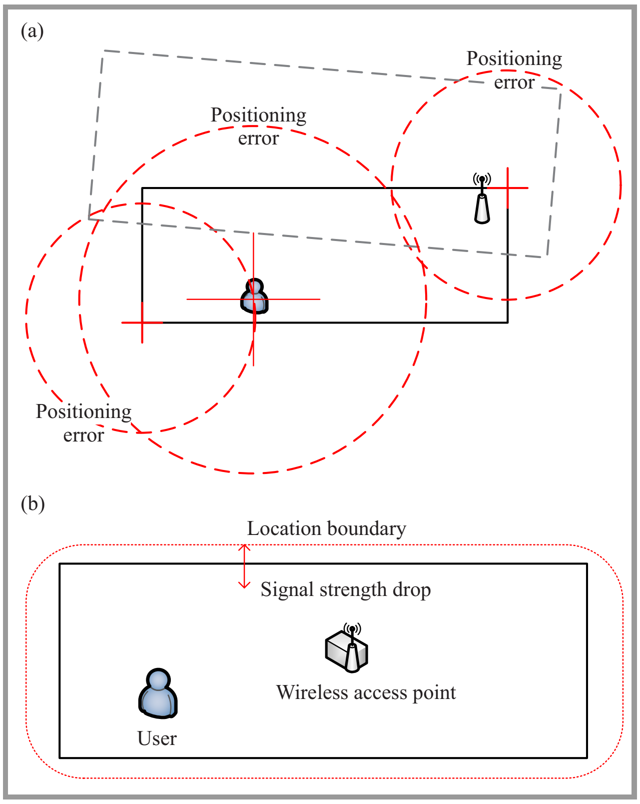

Fig. 3. Public transport vehicle scenario comparison: (a) geolocalization and (b) context localization.

ranges etc. available solutions tend to be costly and offer low transmission throughput (as can be seen in Table 1). Such limitations confine their employment to basic navigational, reporting and safety related applications.

Table 1
Comparison of maritime data transmission systems

System	Transmission type	Throughput
NAVTEX	HF, MF	300 b/s
DSC	VHF	1.2 kb/s
GPS	NMEA 0183	4.8 kb/s
AIS	VHF	2×9.6 kb/s
EPIRB	COSPAS-SARSAT	100 b/h
SSAS		100 b/day
SafetyNET	Extension of NAVTEX to Inmarsat coverage	100 message/day
Other satellite-based systems	Inmarsat, VSAT, ...	64 kb/s – 4 Mb/s

There are, whoever, multiple other uses for broadband data transmission in maritime environment (Fig. 4), especially with recent emergence of enhanced-Navigation (e-Navigation) initiatives, aiming to provide ship officers with comprehensive, integrated services suite for both safety and efficiency of maritime traffic [10], [11].

With obvious inadequacy of currently available solutions, such as expensive satellite communications and range limited shore cellular base stations, the issue of extending the

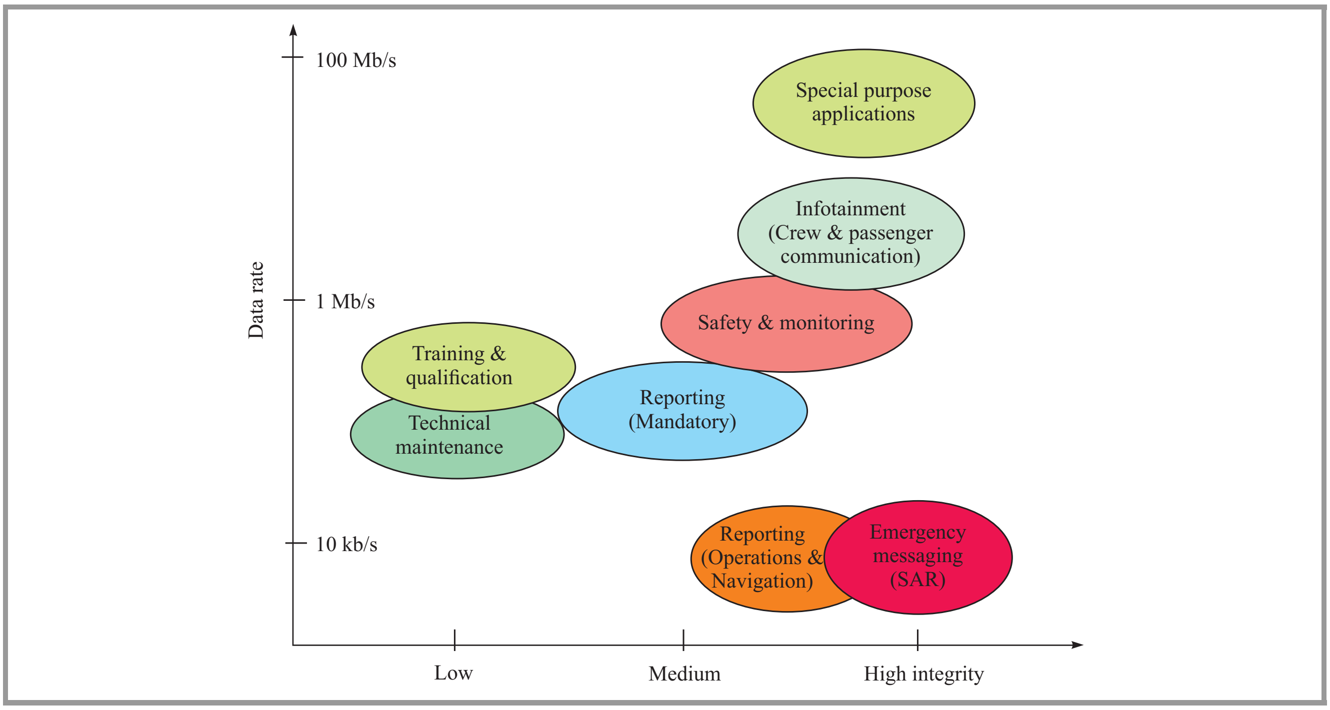

Fig. 4. Maritime services.

availability of broadband network access over sea has been a subject of research at Gdansk University of Technology. Proposed solution includes employment of a number of modern concepts, i.e., self-organizing Wireless Mesh Networks (WMNs), cognitive radio technologies and communication procedures differentiation based on ship location, to create an integrated, self-configuring, heterogeneous network access system. The above mechanisms seem to bring many advantages and facilitate the task of providing ubiquitous network access in diverse deployment scenarios encountered in maritime service.

3. Wireless Access Technologies and Architectures

There are currently many wireless transmission technologies, which can be divided into many groups and types. From author's perspective, the most interested in technologies which can be classified as Wireless Local and Metropolitan Area Networks (WLANs and WMANs). They, supplemented by immensely popular cellular technologies of 2nd to 4th generation (2G-4G, discussed in later section), form practically all popular, and vast majority of all modern broadband network access systems.

While WMAN technologies, such as WiMAX (IEEE 802.16 [12]) are currently deployed only in specific scenarios, being replaced as leading general-purpose, operator-level access technologies by Long Term Evolution (LTE) [13] standards maintained by 3GPP, Wi-Fi WLAN technologies based on IEEE 802.11 family of standards are next to omnipresent in technically developed areas.

Despite the fact that first IEEE 802.11 standard has been proposed over 15 years ago, constant and rapid evolution, driven by actual user needs, has led to its constant and rapidly increasing presence, making Wi-Fi the WLAN technology of choice.

The evolution of Wi-Fi technologies can be divided into 3 distinct stages, corresponding to increasing levels of standard's technological maturity. The first Wi-Fi standard, IEEE 802.11-1997 [14], offered transmission speeds up to 2 Mb/s over radio and infrared media, utilizing contention-based medium access mechanisms. From the network administrator's point of view, it lacked almost all elements and functions necessary for utilizing it as an efficient and reliable element of a complex network system, and had to be regarded as not much more as a proof of concept, showing the possibility of creating a low-cost wireless transmission solution.

In this situation, the first stage of development of IEEE 802.11 standard addressed the most pressing requirements necessary for the discussed technology to be used in production grade systems: available throughput, elements of QoS management and security. As a result it became possible to reach transmission rates up to 54 Mb/s in both 2.4 GHz (IEEE 802.11g [15]) and 5 GHz (IEEE 802.11a [16]) ISM bands. Moreover, multiple optimizations and advanced mechanisms allowing both traffic prioritization and hard QoS guarantees were defined in IEEE 802.11e [17]. However, it was never implemented in practice. On the basis of IEEE 802.11e, Wireless Multimedia Extensions (WME) [18] specification has been developed, covering only traffic prioritization and assorted optimizations of transmission efficiency and power-saving functions.

To address gaping holes of initial Wired Equivalent Privacy (WEP) [14] security mechanisms, an IEEE 802.11i [19] extension has been defined, introducing cryptographically sound suite of security mechanisms. At this point, an IEEE 802.11-2007 [20] release of standard have been published, marking development state allowing the use of Wi-Fi technology in production grade systems, and beginning the second stage of standard evolution.

With the strictly necessary functionality present in IEEE 802.11-2007 standard, further development concentrated on still lacking, monitoring and management tasks. With extensions such as IEEE 802.11k (Radio Resource Measurement) [21] and 802.11v (Wireless Network Management) [22], it becomes possible to improve network efficiency by controlling not only infrastructure devices, but also wireless clients, which have been impossible previously. There are also multiple extensions dedicated to interworking and creation of complex network systems, i.e., IEEE 802.11u (Interworking with non-802 networks) [23], IEEE 802.11r (Fast Roaming) [24] or IEEE 802.11s (Mesh Networking) [25]. Growing ability of Wi-Fi networks to function in complex network environment, created the need for protection of its management traffic, which, up until this point, have been transmitted unprotected as IEEE 802.11i covers only user's traffic protection. For this purpose IEEE 802.11w (protected Management Frames) [26] extension have been introduced. In parallel with these management-related improvements, the work towards improving available throughput is has continued, resulting in IEEE 802.11n (higher throughput improvements using MIMO) [27] specification, allowing for transmission speeds up to 600 Mb/s (depending on number of spatial streams and channel width). There is also a first, service-related extension to Wi-Fi standard – IEEE 802.11p (Wireless Access for Vehicular Environments) [28], dedicated to use of Wi-Fi in vehicular networks.

A new update of main standard follows, marked IEEE 802.11-2012 [29], specifying Wi-Fi as a fully mature technology, with well recognized place in both popular home deployments, corporate networks and sizable access systems.

At present, Wi-Fi technology diversifies to cover multiple possible deployment scenarios. There are some extensions concerning its use for efficient handling of multimedia traffic (IEEE 802.11aa – Robust Audio/Video Streaming) [30], and growing management traffic prioritization (IEEE 802.11ae [31]), but the most prominent are transmission related improvements.

There are concurrently 4 separate extensions being developed, dedicated to radio transmission mechanisms for different usage scenarios:

- IEEE 802.11ac [32] – aiming to provide very high throughput (over 1 Gb/s) in traditional 5 GHz band, suitable for general-purpose popular deployments,
- IEEE 802.11ad [33] – designed for very high throughput (up to about 7 Gb/s), but very short ranged transmissions, suitable for indoor, line-of-sight interactions between mobile devices and infrastructure,
- IEEE 802.11ah [34] – operating at frequencies under 1 GHz, created to extend network coverage at the cost of transmission rate, which makes it well suited for monitoring/automation systems,
- IEEE 802.11af [35] – introduces cognitive radio mechanisms to Wi-Fi, allowing transmissions in unused TV frequency channels.

By adopting such diverse development directions, authors of IEEE 802.11 standards family clearly aim to make it the standard of choice for diverse needs created by varied deployment scenarios necessary for ubiquitous network access.

One of the very interesting elements being introduced to modern wireless access networks (including Wi-Fi) are cognitive radio mechanisms. They allow these networks to utilize radio frequency channels assigned to other technologies, as long as they will not negatively impact functionality of the primary owner of the channel. The most common example involves use of TV Whitespace (unused TV channels) for data transmission. There are currently two such solutions in process of standardization dedicated to the task: IEEE 802.22 [36] and already mentioned IEEE 802.11af [35].

The first, IEEE 802.22 has been designed in point-to-multipoint architecture, to provide Internet access service for stationary or nomadic users over large areas. With typical Base Station (BS) transmission range of 33 km and maximum of about 100 km (Fig. 5), its deployments are categorized as Regional Area Networks (RANs) [35]. The utilized frequency range depends on local regulatory rules, but generally fall in sub-one gigahertz range (for example 54–862 MHz), which ensures good propagation and coverage over long distances. With each TV channel of 6 MHz being used, the system is able to provide asymmetric data transmission rate of 23 Mb/s. As avoiding disruption of primary service take absolute priority, IEEE 802.22 standard includes a number of mechanisms to prevent such occurrence. Each client terminal (Customer Premises Equipment – CPE) is identified by the system and knows its current geographic location, which allows it to consult a dedicated database to obtain a list of RF channels which can possibly be used. Building on that basis, the system gives its BS complete control over CPE activity, which allows fast reconfiguration as needed. Moreover, sophisticated spectrum sensing mechanisms are included in both BS and CPEs, ensuring real-time reaction for presence of primary service signal in channel which has been considered free.

The described technology, apart from improving radio resources utilization efficiency, provides an important tool for providing ubiquitous network access, due to its long range and through coverage. With IEEE 802.22 technology, it becomes relatively easy to provide network access

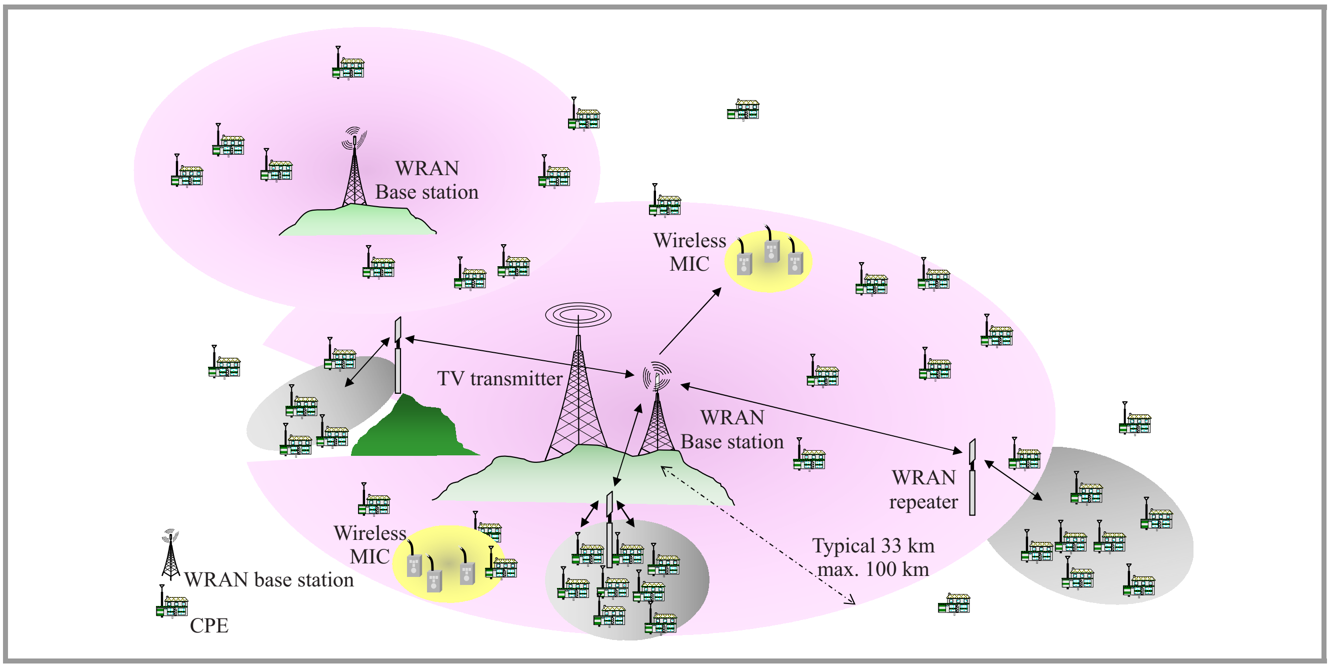

Fig. 5. IEEE 802.22 Regional Area Network.

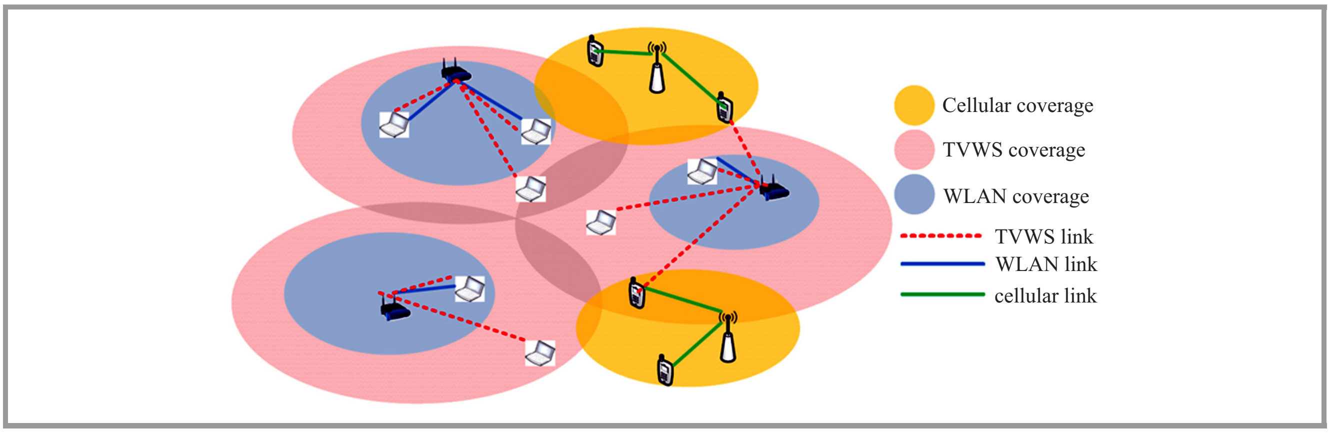

Fig. 6. Predicted usage scenario of IEEE 802.11af access technology.

over extended areas, which can then be supplemented with shorter-ranged, but capable of higher throughput, technologies such as WLANs, WMANs and cellular systems.

The second of the discussed cognitive radio technologies, IEEE 802.11af [36], utilizes mechanisms very similar to these present in IEEE 802.22 technology and also takes TV Whitespace advantage. It is, however, designed for much smaller ranges and with maximum allowed transmission power of 100 mW, can be used to extend range of Wi-Fi APs (Fig. 6) [37]. Despite possible problems of coexistence with IEEE 802.22, this technology promises to close the gap between cheap but very short ranged Wi-Fi coverage and much more costly WMAN technologies (i.e. WiMAX) and cellular systems.

Another of relatively new approaches to providing through coverage without the necessity of deploying extensive, fixed infrastructure consists of deploying a broadband wireless system of devices capable of forwarding received traffic in highly automated manner. Highly developed auto-configuration, dynamic routing, fault management, monitoring etc. mechanisms make such systems a very robust solutions. They are generally labeled Wireless Mesh Networks (WMNs), despite the fact that the description covers at least two popular, yet vastly different approaches to deployment of an access system. The first one, which can be called pre-designed WMN, consists of a number of devices in a network structure designed and deployed by network operator, which take advantage of mesh functions to provide network connectivity for dedicated access points and their connected clients. In this case mesh nodes can be homogenous and possess considerable resources (such as multiple wireless interfaces, crucial for efficient transit traffic forwarding), while the network structure itself can be optimized during design stage.

The second one, which can be described as ad-hoc WMN, allows each connecting client to act as fully functional mesh

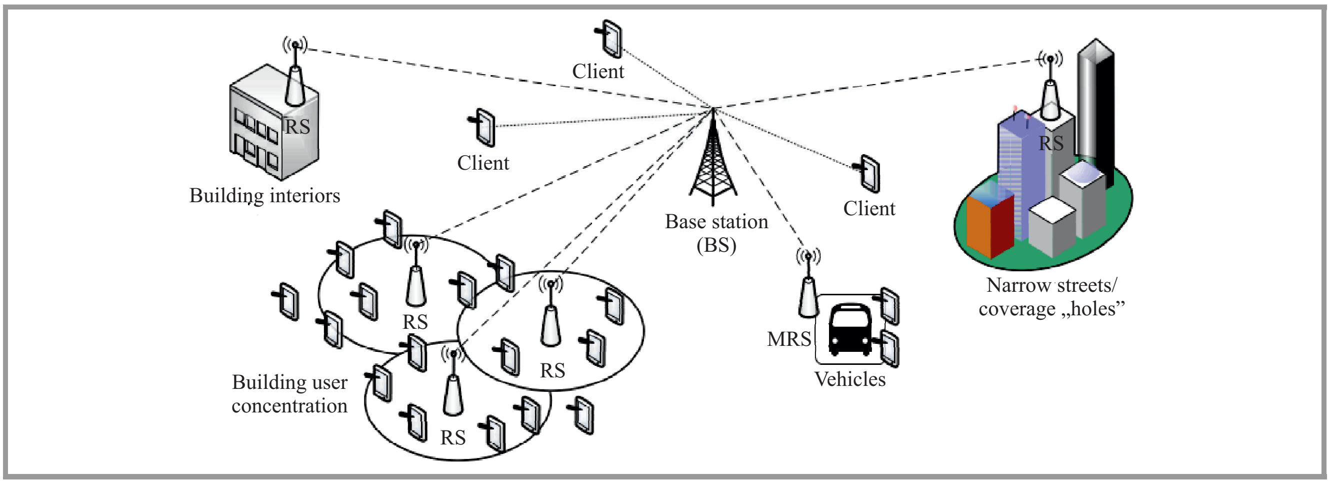

Fig. 7. Relay stations.

node, so each such client can extend its overall traffic forwarding capacity and coverage. Such ability allows a severe reduction of the necessary operator provided infrastructure compared to classic point-to-multipoint systems. It is also a significant step towards network access ubiquity, as such mesh systems tend to provide through coverage even in difficult propagation conditions.

Mesh networks can be used in a variety of roles, starting from small ad-hoc systems, through a highly robust and redundant access network infrastructure, and ending with emergency or military communication networks or self-organizing office/building/campus integrated infrastructure/access systems. In all of these scenarios, the main mesh networks advantages include autoconfiguration and self-forming capabilities.

One of the most promising mesh solutions currently being developed is an IEEE 802.11s standard [25], aiming to create a broadband, fully autoconfigurable, dynamically extending, and secure mesh solution, based on widely popular Wi-Fi technology. It is designed to serve in wide variety of environments, starting with small ad-hoc, isolated networks (for example: laptops or smartphones groups), through industrial/sensor network deployments, office LANs, and ending with large, self-extending, public access systems. The fact that this solution is based on cheap and popular Wi-Fi technology and can be deployed on existing hardware makes it one of very few mesh solutions able to successfully appear and remain on popular WLAN market. Additionally, a number of design decision have been made to make an IEEE 802.11s mesh as compatible and as easy as possible to integrate with existing network systems.

Due to mesh network mechanisms complexity and the fact that described automation level of management functions is rarely necessary in case of pre-designed access network infrastructure, mesh architecture is slow to gain popularity in such deployments. In vast majority they retain classic point-to-multipoint architecture, with base stations acting as points of network attachment to clients. However, due to relatively high cost and infrastructure requirements of fully functional base stations, a relay stations concept have been introduced, which be seen as a simplified form of multihop transmission. Relay stations are responsible for providing network access to clients, but only under direction of already deployed, fully functional BS, which allows them to be significantly simpler and cheaper. Moreover, while BS requires dedicated network connection to the infrastructure, relay station can be connected to its governing BS using the same mechanisms as clients, instead.

As a result, different variants of relay stationscan be deployed (Fig. 7) – starting from simple range extenders utilizing in-band communication with governing BS, through somewhat more costly ones which can to be chained forming multihop structure, and ending with versions able to internally perform most operations necessary for servicing clients and are useful for offloading governing BS in areas of high client density.

Examples of technologies which define relay stations include more advanced WiMAX variants (IEEE 802.16j [38]) and already mentioned IEEE 802.22 [35].

With such diverse access technologies at our disposal it is natural, that access system providers will differentiate deployed technologies to best suite their technical and economic needs. Even if a single access network of particular operator will have homogenous composition, the network environment of a mobile end-user interested in retaining ubiquity of access will be a heterogeneous one. In this situation, presence of efficient mechanisms for handling a seamless change of his point of network attachment, both within the structure of a single access network and across their boundaries, is of utmost importance. The tasks required for this process can be roughly divided into two processes:

- handover support – ability to seamlessly connect to new point of network attachment and configure all necessary mechanisms for network access;
- mobility management – ability to retain client's identity and current network sessions despite handover, to allow for continued high-layer service access.

4. Handover Support

Ability to change a point of network attachment in a manner which will minimally disrupt network connectivity of a mobile user is a task of paramount importance in modern access systems. The process is not a straightforward one even in within a homogenous system under consolidated management, and it only gets more difficult when we need to perform it across administrative network boundaries or between two different access technologies.

Due to the task complexity and many different scenarios which contribute to its necessity, taxonomy of handover types and solutions is an extensive one [39], which makes it impractical to include in this paper. Instead, a review of some general areas for process optimizations and a few chosen approaches to the problem in example environment of the most popular WLAN technologies are presented.

The handover process in general can be divided in to a number of distinctive phases, including:

- handover detection – decision that it is necessary to perform handover. In case of some simple WLAN technologies it amounts to detection that client alredy lost network access;
- network search – obtaining information about new access networks possible for client use and choosing the one to connect to;
- association – attempt to connect to a chosen network;
- authentication – providing authentication information for new network's access control mechanisms. Theoretically optional, in practice a required step;
- higher layers configuration – after obtaining link-layer connectivity, it is necessary to reconfigure higher layer (mostly network layer) mechanisms.

Example time values necessary to perform the above steps in case of popular Wi-Fi technology and IP-based network are provided in Table 2.

Table 2
Comparison of maritime data transmission systems

Layer	Item	Best case [ms]	Worst case [ms]
L2	802.11 scan (passive)	0 (cached)	1000
	802.11 scan (active)	20	300
	802.11 association	4	80
	802.1x auth (full)	750	1200
	802.1x fast resume	150	300
	Fast handoff	10	80
L3	DHCPv4	200	500
	IPv4 DAD	0 (DNA)	3000
	IPv6 RS/RA	5	10
	IPv6 DAD	0 (optimistic DAD)	1000
	MIPv6 MN->HA	0	200

Some stages of the handover process can introduce significant delays – in particular, network search and authentication. Moreover, IP configuration, which includes obtaining a new IP address and verification if it is not duplicated by Duplicate Address Detection function can be quite lengthy. If we take into account, that Wi-Fi utilizes hard-handover, which means that existing connection is released as first step of handover process, each delay results in longer disruption of client's connectivity. Many approaches to handover optimization have been proposed, for example IEEE 802.11r [24] extension of Wi-Fi standard includes fast resume/fast handoff mechanisms which allow for drastic reduction of authentication phase.

In this situation, during author research activity at Gdańsk University of Technology the issues related to network search phase was addressed. By performing network search while the client is still connected to its current access point, significantly reduce handover time and resulting disruption of services can be achieved. However, if reduction QoS of existing network connection is unwanted, this process of background scanning can be a lengthy one, poorly suited for fast moving users. In this situation be decided to use a dedicated, physical interface for this purpose, which solved the problem and allowed to use much more sophisticated criteria in choosing new access point than simply current signal strength. Example results of experiment combining the described handover optimization with Proxy Mobile IPv6 mobility management protocol implementation (see Section 5) are presented in Table 3. The experiment consisted of a single Wi-Fi handover during MPEG (2 Mb/s) video transmission. For estimation of QoE level a Degradation Category Rating (DCR) 5 points MOS scale has been employed [40].

Taking the research further in this direction, the author decided to make the disruption of network connectivity largely independent of handover time, by introducing soft-handover to Wi-Fi technology. In this case the described preemptive scanning is performed and when decision handover is made, the connection to old access point is not disconnected, until a new one is finalized. By use of this method at most one IP packet at handover is lost, which makes it next to transparent to user [41].

Implementation of the above mechanisms utilizes standard tools of popular operating systems introducing only additional management functions by means of scripting language, which makes it both highly universal, compatible, hardware independent and suitable for vertical (inter-technology) handover [40], [41].

Another approach to handover optimization have been demonstrated by concept of Virtual Cell [42], made possible by popularization of wireless installations based on Wireless Network Controller (WNC) architecture. In their case, instead of multiple fully functional access points (APs) able to forward network traffic between wireless and wired network by generally recognized rules, there is only one central entity responsible for traffic handling, and all

Table 3
Impact of IEEE 802.11/PMIPv6 handover on MPEG video transmission

Scenario	No. handover	PMIPv6 with standard handover	PMIPv6 with optimized scanning
MOS (DCR)	4.86 ±0.09	2.34 ±0.17	3.98 ±0.14
Mean delay delta [ms]	3.98 ±0.001	4.99 ±0.05	4.63 ±0.04
Mean jitter [ms]	3.97 ±0.001	4.97 ±0.05	4.61 ±0.04
Mean packet loss	78 ±37	3498 ±500	1065 ±250
Connectivity gap [s]	–	5.05 ±0.78	1.45 ±1.00

access points (called Lightweight Access Points – LWAPs) are responsible sorely for forwarding it towards WNC. Such an approach, while creating evident problems with scalability, provides level of control over network system which have not been possible before. Proprietary Virtual Cell technology takes even more radical approach – the WNC is able to control activity of APs to the extent which makes it possible for the network to be presented to standard Wi-Fi client as a single virtual AP which relocates between hardware APs, following the client. As a result, client never experiences link layer handover and disruptions of his connectivity related to virtual AP relocation do not exceed 5 ms. At the same time, there is no need to differentiate frequency channels between neighboring APs, as WNC is able to coordinate transmissions (including that of standard Wi-Fi clients) to avoid interference. That, in turn, makes it possible to place APs in much denser manner, thereby extending system capacity as client number is concerned.

Apart from the above techniques, designed to improve link layer handover processes efficiency, there are also similar solutions for network layer-related handover stages. For example, it is a popular approach to omit DAD procedures, relaying on proper functioning of address assignment solutions, and accepting marginally probable address conflicts, to obtain significant improvement in handover performance.

5. Mobility Management

However, even efficient handover itself does not guarantee, that mobile user will be able to continue his activities uninterrupted. It is highly probable, that, due to change of location in network structure, his network address will also be changed, resulting in disconnection of existing network sessions. To prevent such occurrence, it is necessary to employ mobility management mechanisms.

Despite the fact, that there are various sets of network layer mechanisms, the author is going to concentrate on IP-based networks, as by far the most popular ones. Moreover, many problems of efficient mobility support encountered in IP networks are also valid for different network layer solutions.

The single most important consideration is the fact, that an address in IP network serves dual purpose – it both uniquely identifies the client and describes its location in a network structure. Due to this characteristic, a change in client's point of network attachment significant enough to place him in different location within network-layer system structure, must also result in change of his IP address – which, in turn, results in change of his identity, as far as network mechanisms are concerned. To prevent such occurrences and allow the user to preserve his network sessions continuity, a number of mobility management mechanisms have been proposed. The most universal approach is to implement them in network layer, thus allowing them to provide mobility support for different higher layer protocols and applications in transparent manner (for example by allowing the client to retain his IP address). However, this approach requires a network protocol stack modification and additional mechanisms inclusion.

Such requirements resulted in slow deployment of network layer mobility management solutions, and significant number of application layer solutions have been deployed instead [43]. They perform efficiently for a single specific application or service. There are also some propositions of mechanisms located in other ISO-OSI layers, for example in transport layer, but they have not gained significant popularity.

To provide ubiquitous network access, the network layer mobility management is most interesting, due to mentioned transparency for higher layer mechanisms and independence of lower layer transmission technologies. In their case, available solutions can be divided into three groups, based on general architecture of a given solution:

- client-side solutions – require additional mechanisms to be included in client's network protocol stack, but will function in any access network;
- network-side solutions – all necessary mechanisms are located within an access network, while client equipment need not to be modified in any way;
- mixed solutions – require both client device and access network mechanisms modification.

From the above groups, mixed solutions are relatively poorly suited for this purposes, requiring both network devices of access systems and client devices modification, which complicates their popular deployment. This group includes well known Mobile IPv4 [44] protocol, developed over 18 years ago, which functions in a manner very similar to client-side Mobile IPv6 [8] solution described below, but, due to limitations of IPv4 protocol, requires additional element to be present in access network being currently used by mobile client.

Client-side solutions, such as Mobile IPv6 [8], allow modified client devices to retain their IP address as they move through unmodified access systems. This is a powerful ability as far as ubiquitous mobility support is concerned, providing users with global mobility support (macro-mobility – see Fig. 8). Moreover, the emergence of a relatively small group of general purpose operating systems for mobile devices, makes the requirement of client-side IP protocol stack modification an actual possibility even in mass deployments.

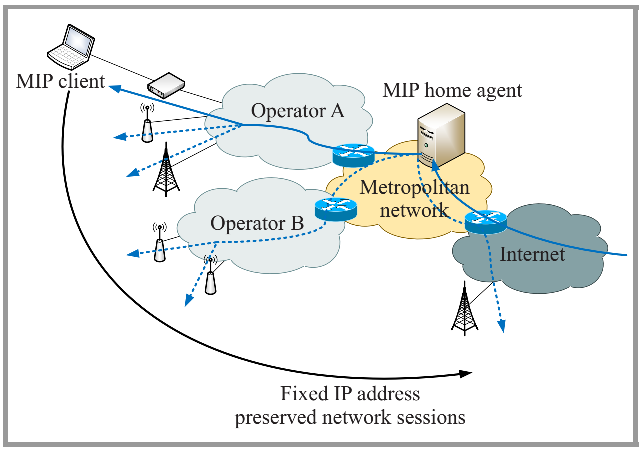

Fig. 8. Mobile IPv6 client-based mobility management solution.

Its basic principle of operation involves the client (called Mobile Node – MN) possessing two IP addresses: an unchanging home address and a Care-of-Address (CoA) obtained in visited access network. After obtaining CoA, MN contacts Home Agent (HA) entity responsible for managing its mobility and registers a mapping between its home address and current CoA. The traffic for MN's home address is routed to HA, which delivers it, by means of tunneling, to CoA registered by MN. Traffic in opposite direction can be delivered using standard IP mechanisms (resulting in possibly harmful triangle-routing) or by using reverse tunnel from MN to HA.

Network-side solutions, in contrast, allow unmodified clients to retain their IP addresses, as long as they move within access network where this solution has been deployed. Such characteristics makes their general deployment more problematic than in case of client-based solutions, but ability to support any client device in a transparent manner can be highly beneficial. The most popular example of this approach is Proxy Mobile IPv6 [45]. In its case, access routers (called Mobility Access Gateways – MAGs) are responsible for detecting that client has moved between them, and will inform Local Mobility Anchor (LMA). LMA then tunnels the traffic to appropriate MAG, to be delivered to client (Fig. 9). To provide mobility service transparency, new MAG also impersonates the previous one, by assuming the same link layer and network layer (IP) address.

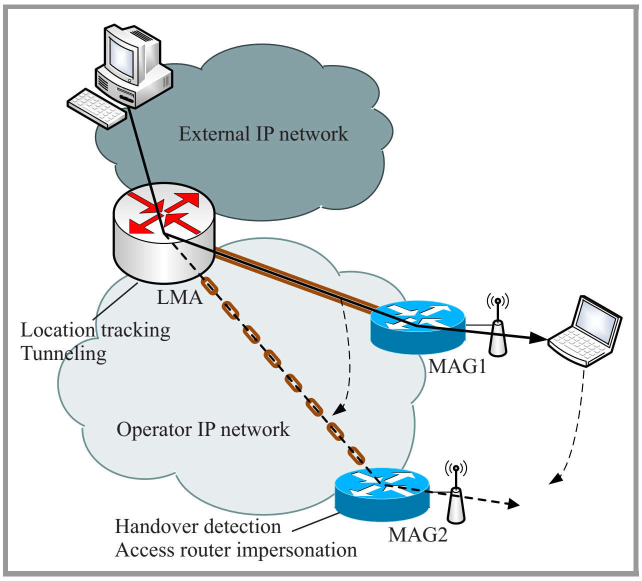

Fig. 9. Proxy Mobile IPv6 - network-based mobility management solution.

As was already mentioned in Section 4, presented research concerning mobility and handover support mechanisms resulted in fully functional implementation of PMIPv6 protocol, complete with related security feature (authentication, accounting, confidentiality and traffic transmission integrity) on Linux platform [40]. It is interesting to note, that such an implementation has been possible to create with exclusive use of scripting language (with associated ease of deployment and high level of compatibility) while still retaining high performance. This possibility derives from the fact, that the necessary functionality falls into management category, while performance intensive data handling functions are readily available in most of modern operating systems.

6. Cellular Network Evolution

When discussing ubiquity of network access it is impossible not to mention modern cellular telephony networks, due to both their popularity and almost universal coverage in technically developed areas. Until recently however, development of the above technologies (standardized mainly by 3GPP [13]) proceeded separately to popular WLAN/WMAN solutions and has been aimed at different goals. Discussed systems have been created as means of commercially providing users with relatively small and well defined services set, mainly related to direct human communication. In this situation it is natural, that standardization moved towards solutions allowing creation of a tightly integrated, homogenous system, complete with a comprehensive management mechanisms set. Specification also took full advantage of clearly defined service set, which

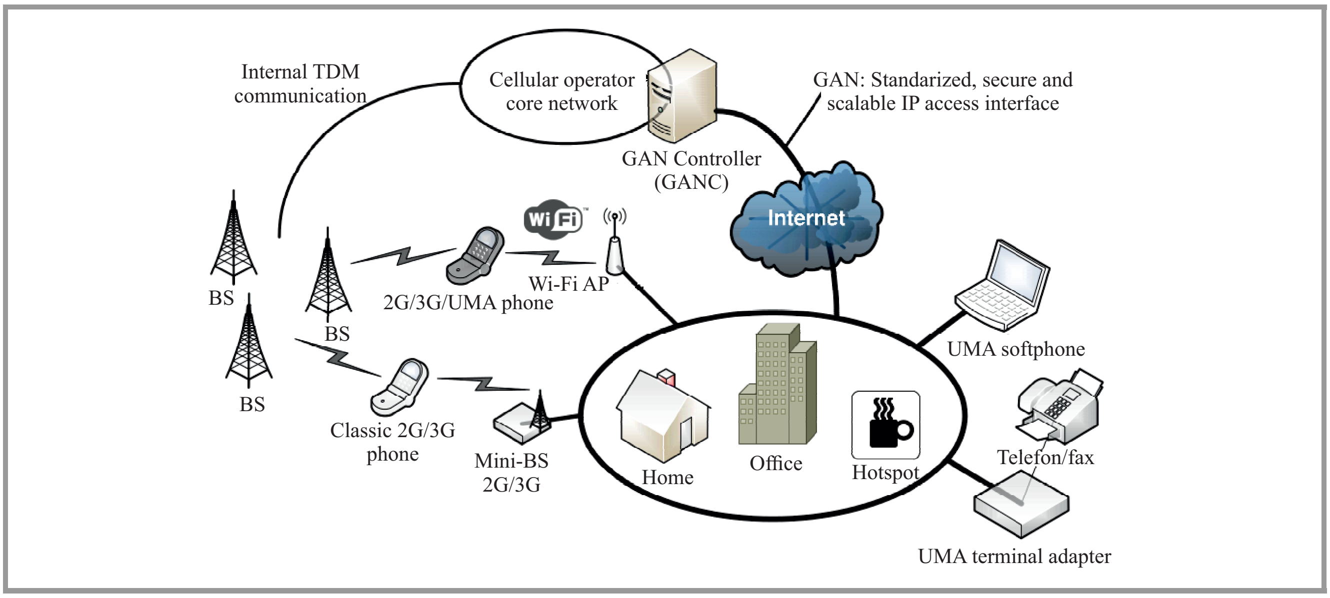

Fig. 10. Generic Access Network structure.

allowed significant simplifications in utilized mechanisms, compared to general purpose system.

It is worthy of note, that the first of the popular digital cellular communication systems, called Global System for Mobile Communications (GSM, 2nd Generation – 2G) provided only channel switching capabilities. Packet switching has been introduced later, in its first modernization: Enhanced Data Rates for GSM Evolution (EDGE – 2.5 Generation – 2.5G), by introducing additional elements to GSM infrastructure and retaining clear separation between channel and packet switching subsystems.

As user demand for additional services requiring packet data transmission started to grow, somewhat ad-hoc introduced packet switching capabilities of EDGE system have been substantially upgraded and tightly integrated with system infrastructure in Universal Mobile Telecommunications System (UMTS, 3rd Generation – 3G) network. Apart from higher possible data rates, there is also a visible trend towards simplification of Radio Access Network (RAN) which is a system part responsible for managing base stations and connecting them to the core network, by limiting number of separate elements and integrating their functions within base stations (called NodeBs).

At this point, with efficient packet switching capabilities of 3G system, first significant initiatives to integrate cellular and computer networks are observed. One of the most interesting is creation of Generic Access Network (GAN) specification, also known as Universal Mobile Access (UMA) technology, which defined mechanisms required to obtain access to services provided by cellular operator's core network with use of IP protocol (see Fig. 10).

By allowing such access, it become possible to obtain services provided by cellular communication network independently of access technology, as long as IP communication of sufficient quality could be maintained between a client and a GAN Controller (GANC). Moreover, client accessing services by means of GAN is always directly connected to his home network and able to access all of its services.

This revolutionary step has been a first standardized and widely recognized move towards new approach to services in communication networks. To date, it was the network that provided certain services to which users could subscribe. With the new approach, there are users, interested in obtaining access to a number of services, which they can access using different network access systems. Such an approach, combined with All-IP trend (providing all possible services by means of IP communication) and aim to provide ubiquity of network access by means of heterogeneous access systems, pointed the way towards the latest development in cellular communications – 4 Generation networks (4G), named Long Term Evolution Advanced (LTE Advanced) [13].

In case of 4G network the existing 3G infrastructure have been abandoned entirely, to be exchanged for RAN in form of a distributed set of sophisticated Enhanced NodeB (eNodeB) base stations, interconnected by IP protocol (over any available transmission technology) amongst themselves and with core network (Fig. 11). This independence of transmission technology (in contrast to a strictly defined allowable technology set of previous generations) allows for much easier deployment and maintenance of infrastructure, enables infrastructure sharing etc. Moreover, new core network architecture (Evolved Packet Core – EPC) also exclusively utilizes IP communication.

Such an architecture also makes it easy to provide support for GAN, but 4G network moves the idea two steps further, by providing mechanisms to integrate computer network technologies (such as WLAN, WMAN, cable modems, etc.) directly with EPC and by moving services outside of network core – 4G network does not provide any services itself, except packet data transmission. This ability and design decision should be considered an enormous step to-

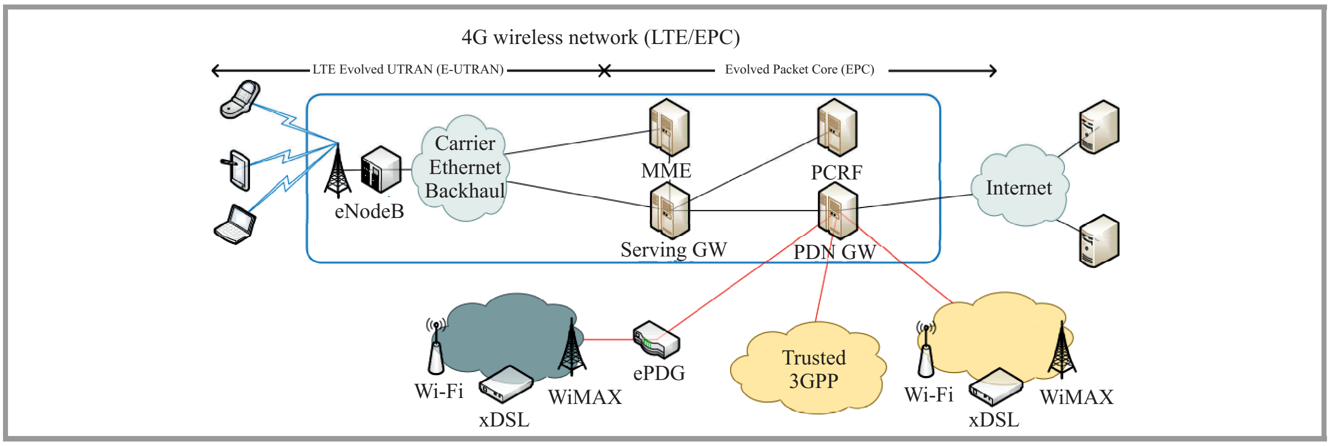

Fig. 11. 4G (LTE Advanced) network architecture.

wards integration of two separate, immensely popular network access technology types, and reconfirms All-IP-based, access agnostic approach to services.

Another element worthy of note is the fact, that 4G network employes well-known IP-based mobility management solutions to provide users with mobility support – for example: mobility of 4G users moving between eNodeBs belonging to different Serving Gateways (see Fig. 11) is supported with use of PMIPv6 [45] and mobility within connected computer network access technologies is supported with use of MIPv4 [44], PMIPv6 [45] or Dual Stack MIPv6 (DS-MIPv6) [46].

7. Conclusions

The provided general survey of various aspects related to a growing need for ubiquitous network access clearly shows that evolution of many separate elements, such as transmission techniques, access network technologies, system architectures and high layer software solutions begin to converge towards this difficult, common goal. Feasibility of successfully reaching this objective in real-world deployments, combined with emergence of approaches such as All-IP, XaaS and cloud services, seem to bring a real possibility of obtaining not only ubiquitous network access, but also to ubiquity in access to high layer services.

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