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Management and Operations of 4G Networks

Computer Science

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ABSTRACT

The 4G network environment is envisioned to be an inter-working environment of heterogeneous networks of 2G, 3G, and 4G all interconnected through the service provider IP backbone networks and the Internet. The operations and management of such interconnected networks is expected much more difficult than the current environment. This paper examines the challenges and defines the requirements for operation and management of the 4G network environment.

1. Introduction

With the introduction of the first generation (1G) mobile communication systems (e.g., Advanced Mobile Phone Service, AMPS) in the 1980s, ordinary people were able to communicate with others with voice while they are on the move. Then with the second generation (2G) mobile communication systems (e.g., Code Division Multiple Access, CDMA, Global Systems for Mobile Communications, GSM) in the early 1990s, people were able to communicate not only with voice but also with text messaging. With the introduction of the third generation (3G) mobile communication systems (e.g., Wide-band Code Division Multiple Access, WCDMA, also known as UMTS and International Mobile Telecommunications-2000, IMT-2000, CDMA 2000 in the late 1990s, people were able to communicate with more data-centric services and applications. Although multimedia communication is possible with 3G systems, scalability and cost have been problems preventing wide deployment thus far. The 4G networks are expected to support a variety of personalized, multimedia applications such as multimedia conferencing, video phones, video/ movie-on-demand, education-on-demand, streaming media, multimedia messaging, etc. Personalized services will be supported by personal mobility capability, which concentrates on the movement of users instead of users' terminals, and which involves the provision of personal communications and personalized operating environments. Driven by the need to support context-rich multimedia services and applications, the fourth generation (4G) mobile communication systems have been under development by researchers and vendors around the world . 4G systems are expected to be deployed and operational within the next several years. With the advances in networking, multiplexing, scheduling and physical layer technologies, 4G systems are also expected to provide higher bandwidth to more users and thus provide more cost-effective services than 3G systems.

The 4G networks are expected to co-exist and inter-work with existing 2G and 3G mobile communication systems as well as satellite, wireless LAN (WLAN), and IEEE 802.16e (also known as Wireless MAN (WMAN) or WiMAX) networks, all interconnected through the service provider IP backbone networks and the Internet as illustrated in Figure 1. In this heterogeneous networks environment, in addition to the traditional challenges such as roaming, horizontal handoffs, security, quality of service (QoS) support, and charging, new challenges such as vertical handoffs, network choice selection, and global roaming exist and must be met with appropriate solutions.

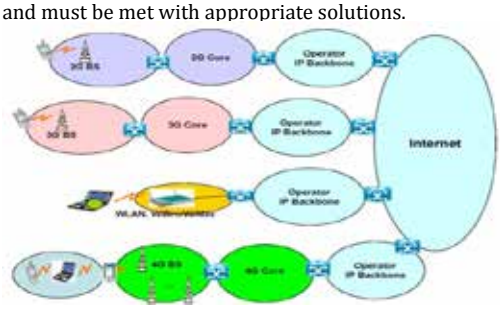

Figure1. Heterogeneous Inter-working 4G Network Environment

Effective, secure and efficient operations and management of the envisioned 4G network environment is a huge challenge. Traditional network operations and management methods and protocols such as CMIP, TMN , SNMP, WBEM themselves are not going to be sufficient enough to support such complex communication and service environment. New, intelligent, and self managing operations and management architectures and methods are needed to meet the challenges. Some research on managing next-generation wireless networks and services has started but a lot more work is needed for efficient and effective operations and management of 4G networks and services. This paper examines the challenges facing the 4G network environment and defines the requirements for meeting the challenges.

2. CHALLENGES IN 4G NETWORK ENVIRONMENT

In the 4G network environment, we envision and assume the co-existence of old and new networks and inter-working of heterogeneous networks as illustrated in Figure 1 will be provided through the cooperation of service providers around the world. This is a very ambitious goal and there are many challenges that must overcome before this vision can be realized. In this section, we examine each challenge.

2.1 Network Discovery and Selection

Each terminal device used in 4G networks will be multi-mode, multi-access and reconfigurable. That is, each terminal can be using more than one type of network and possibly access multiple networks simultaneously for different applications (e.g., one for voice and another for receiving streaming media). In such an environment, a terminal must be able to discover what networks are available for use. One of the proposed solutions for network discovery is to use software radio devices that can scan the available networks. After scanning, they will load the required software and reconfigure themselves for the selected network. The software can be downloaded from media such as a server, smart card, memory card or over the air. A more challenging issue is which network to select when multiple networks are available for use. A greater challenge is to discover the networks and select the network when a handoff is necessary. When there is more than one choice, which network do you choose? Is the decision made manually or automatically? Without a doubt, it would be desirable for the device to select the network automatically, possibly with the help of some intelligent service in the network. Such a decision must be made fast enough in order to avoid any continuation problems in the service. The greatest challenge is to select the network that will satisfy the QoS requirements of the current service and that will be the most economical. A lot of work needs to be done in this area as this is a new challenge imposed in the 4G network environment.

2.2 Handoffs

In 2G and 3G networks, only one type of handoff is needed, namely the horizontal handoff, which involves a terminal device to change cells within the same type of network (e.g., within a CDMA network) to maintain service continuity. There has been a lot of research work in improving the handoff functionality by allowing faster handoffs and thus reduce the possibility of network disconnection . In 4G network environment, in addi-

tion to the horizontal handoff, the vertical handoff must also be supported . The vertical handoff mechanism allows a terminal device to change networks between different types of networks (e.g., between 3G and 4G networks) in a way that is completely transparent to end user applications. Thus, the challenge is to allow vertical handoffs between pairs of different types of networks in the presence of 2G, 3G, WLAN, WMAN, satellite, and 4G networks. The greater challenge lies when the vertical handoffs must take place with a certain set of QoS requirements still satisfied.

2.3 Roaming

Roaming allows a cellular customer to automatically make and receive voice calls, send and receive data, or access other services when travelling outside the geographical coverage area of the home network, by means of using a visited network. Roaming is technically supported by mobility management, authentication and billing procedures. Establishing roaming between service providers is based on roaming agreements. If the visited network is in the same country as the home network, this is known as national roaming. If the visited network is outside the home country, this is known as global roaming. If the visited network operates on a different technical standard than the home network, this is known as inter-standard roaming. In 4G networks, all three types of roaming will need to be supported to roam different network types operating in different cities and countries. For true global roaming, roaming agreements must be set up among service providers in a country as well as in different countries. Today, only a few service providers in different countries provide global roaming. The challenge is to provide more roaming agreements among the service providers in different countries. The greater challenge would be to provide inter-standard roaming as well in different countries.

2.4 QoS Support

Over the past decade a lot of research has been done in the area of QoS. Many protocols and methods have been proposed. However, the predominant method to support QoS by the Internet service providers (ISPs) today is over-provisioning. That is, instead of implementing complex QoS algorithms and methods, ISPs typically provide enough bandwidth in their backbone trunks so that their networks are hardly overloaded and thus there exists very little delay and few packets are lost in transit. This is quite feasible since a lot of fiber trunks have been installed over the past few years and the bandwidth cost of wired Internet trunks is very cheap. In the ISP's views, it is much simpler and cheaper to provide over-provisioned networks than implementing and managing complex QoS mechanisms. Although the 4G networks are supposed to provide higher bandwidth and more cost-effective channels than its predecessor networks, the bandwidth cost in 4G wireless networks will remain higher than wired networks. Thus, over-provisioning in 4G networks will not be feasible and QoS support mechanisms will definitely be needed. Providing QoS support in 4G networks will be a major challenge and a lot of work is needed to meet the challenge.

2.5 Charging and Billing

Internet access is widely available from ISPs for use by using a number of access technologies including xDSL, cable modem, FTTH, satellite, and leased lines. The charging models for these traditional Internet access networks are already established and in use around the world. These established charging models are now being applied with limited success to the new and evolving Internet access networks including WLAN and mobile telecommunication networks offering 2G and 3G services. Limited global roaming and connections between wired and wireless telecommunications are possible through cooperation among the service providers with settlement agreements. Termination fees and charges are part of the agreements, which state which service provider pays which other service provider for communication charges in one direction and vice versa. In the 4G network environment, multiple service providers will typically be involved during a session (e.g., a phone call and data access), which may roam from one service provider network to one or more other service provider networks. Thus, a single session may incur a number of charges, each of which may be for different service provider. Moreover, different charging schemes may be used for different types of services (e.g., charging can be based on data, time, or content). One challenge is to keep track of charges per use per segment of a session that used their network, service or content. There will need to be more charging agreements between the service providers in order to allow roaming during a session in order to get a continued service as far as a customer is concerned. In this environment, customers must be subscribed to multiple service providers and are faced with multiple bills at the end of each month. It would be very convenient for a customer to subscribe to a single service provider and get a single bill but still use whatever networks and services that they would like to use. In order to achieve this, a brokering service can be used.

3. Operations and Management requirements

In the early 1980s, the first operations and management standard called ISO-OSI Systems Management Framework was made. At that time, the standard had identified five functional areas, namely Fault management, Configuration management, Accounting management, Performance management, and Security management (FCAPS). These five functional areas were sufficient to cover most, if not all, of the issues related to the operations and management of the wired networks including the Internet and enterprise networks. With the introduction of wireless and mobile networks few additional areas, which could not be easily covered by FCAPS, had to be added. They are Mobility management, Customer management, and Terminal management. These functional requirements are illustrated in Figure 2.

3.1 Fault Management

The 4G network environment will consist of numerous network devices such as base stations (BSs), access points (APs), gateways (GWs), routers, and servers to be monitored and controlled. These devices will certainly be equipped with management agents (e.g., SNMP, CMIP), that will provide various information for the requests made by one or more managers. As being done now, faults (or also generally called problems) of devices will be managed by each of the service providers that own the devices. Due to the increased number of devices to cover more geographic areas and users, and the number of types of devices, scalable fault management solutions are desirable. Devices are likely generate more event (including problem) reports as they will be involved in handoffs, roaming, charging, etc., and thus there will be a lot more event reports to be processed than in the traditional networks. Logging and auditing of events will be a challenge but will need to be provided. Hence, traditional ways of doing fault management will not likely scale well in the 4G network environment. One possible solution is to apply the concept of "autonomic computing", where devices will be more self-managed.



Figure 2. Required Operations and Management Functions for 4G Network Environment

3.2 Configuration Management

For the 4G network environment, we have identified three subareas in configuration management that must be supported.

3.2.1 Device Configuration and Re-configuration

Device configuration management is one of the hardest management functional areas even in the wired networks. IETF has recently formed a working group, called Netconf, whose goal is

to provide a standard mechanism for transferring configuration data to and from a device, and for examining device state information which may impact the configuration. This standard way of configuring and reconfiguring of devices will allow devices from different vendors to be managed in a uniform way and to reduce the human intervention and thus minimize incorrect settings in the devices. This standard method can be easily extended to the devices in the wireless and mobile networks. This is absolutely desirable as the terminal devices in the 4G network environment will be multi-mode and multi-access capable. Devices can be automatically or manually configured to access a certain type of network and their capabilities and status can be automatically registered or notified to the configuration management system in the networks.

3.2.2 Network Discovery and Selection

One of the challenges in the 4G network environment, a terminal device must be able to discover what networks are available for use and select which network to use. This must be also possible when a handoff is necessary. The device must also be able to select the one, if available, that satisfies the current session's QoS requirement. Thus, a network discovery and selection mechanism must be provided. Ideally, the selection is done intelligently and automatically based on the most economical choice out of the available ones for the user. Since the handoffs must take place very quickly in order to provide continued service without the user's intervention or even the user knowing that a handoff is taking place, the discovery and selection mechanism must be done in real-time within the given time constraint.

3.2.3 Network and Service Provisioning

When a customer subscribes for a network access service, appropriate network resources must be allocated so that the service can be provided. Similarly, when a customer subscribes for a one or more application services, the subscription must be registered and appropriate resources must be allocated. These aspects are closely coupled with resource management and planning.

3.3 Accounting Management

Accounting management largely entails Authentication, Authorization and Accounting (AAA), Charging, and Billing. These have been traditionally important functionalities, particularly to the service providers since through this the service providers bring in the revenue from customers. Accounting management in the 4G network environment is also very important and robust, precise and inter-working accounting systems are required.

3.3.1 Authentication, Authorization and Accounting (AAA)

Users wishing to use one or more services provided by the service providers must be authenticated (i.e., validate who the user is) and authorized (i.e., validate whether the user is allowed to use the service). After that, the user can enjoy the service and be charged according to what the user did. One of the most difficult challenges the 4G network environment will face is in providing authentication and authorization service in real-time so that when roaming is required, the user can be authenticated and authorized to change the network on the fly. It makes even more challenging when roaming combined with vertical handoff and QoS requirement satisfaction checking is required on the fly. IETF AAA Working Group has standardized AAA based on RADIUS and is now working on AAA based on DIAMETER. It will be interesting to see whether DIAMETER will be sufficient for AAA in the 4G network environment.

3.3.2 Charging and Billing

A single user session may involve one or more service providers' networks in the 4G network environment. Also, within the same service provider, a session may involve multiple types of networks (e.g., WLAN, 3G, 4G) which may have different charging schemes. Billing needs consider variable rating due to service bundling (e.g., mobile phone, Internet access, satellite TV, etc.) A session manager would keep track of the user's activities during a session. A charging system needs to exist in each service provider network that keeps track of the individual customer's usage. Service providers in turn would periodically settle charges with other service providers based on the settlement agreements setup between the service providers. A billing system keeps track of customers' charges and generates monthly bills. It also keeps track of overdue payments, credits, etc.

3.4 Performance Management

Performance management is another essential required management areas for the 4G network environment. This is especially true as most of the service providers today consider performance assurance as a key part of service level agreement (SLA) that they make with the customers when they subscribe. At lower level, network performance monitoring is required and at upper level, service quality management is required.

3.4.1 Performance Monitoring

For network performance monitoring, an active monitoring method is typically used, where packets are sent in to the network to obtain performance metrics such delay, jitter, packet loss, and throughput. Performance testing probes are typically placed in key major locations in a service provider network and periodically (e.g., once a minute) sends probes to each other to determine how their networks are performing. These performance figures are either provided to the customers as requested (or via a network weather website), or used for service quality management to verify that their networks are performing according to the agreements they made with the customers via SLAs.

3.4.2 Service Quality Management

Service Level Agreement (SLA) is a formal negotiated agreement between a service provider and a customer. The service quality management (SQM) is the integrated management of all functionalities in the SLA life cycle. When a customer orders a service from a service provider, an SLA is negotiated and then a contract is made. In the SLA contract, QoS parameters that specify the service quality that the service provider will guarantee are included. The service provider must perform SLA monitoring to verify whether the offered service is meeting the QoS parameters specified in the SLA. SLA monitoring involves monitoring the performance status of the offered service and provides relevant information to the service quality management system. In order for the service quality management system to verify whether the specified QoS parameters are being met, the system must gather performance data from the underlying network performance monitoring system and map such data to the QoS parameters.

3.5 Security Management

Other than the AAA requirement described above already, information security and network security are two important aspects of security in the 4G network environment. Both aspects are important to the integrity of the communication or data being transferred and for the health of the network resources including the networks and servers providing the services.

3.5.1 Information Security

Cryptography can be used to encrypt and decrypt packet data while in transit to provide secure communication. A lot of research has been done in this area and results such as AES. A disadvantage of using cryptography is the degradation in the performance. Secure communication may not always be necessary. Service providers must determine where cryptic communication would be necessary and may apply only when and where needed.

3.5.2 Network Security

Firewalls, intrusion detection systems (IDSs), and intrusion prevention systems (IPSs) will be needed in key places in the network to protect resources from potential hackers and worms. Anti-virus software must also be installed in key servers in order to detect and cure viruses. Again, these protective measures may degrade the performance of networks and servers but it is well advised to invest and deploy those measures wherever necessary. Hackers, worms and viruses will always exist and they will always out do whatever the protection mechanisms service providers may deploy. Thus, it is always a good idea to constant-

ly keep them up to date and replace to new systems when patching and updating will no longer be effective.

3.6 Mobility Management

Mobility management in the 4G network environment entails horizontal and vertical handoffs, and roaming , both horizontal and vertical handoff functionalities must be provided in the 4G network environment and a mobility management system is required to support them. A key challenge will be when changing a network for a session with certain QoS requirements. If the QoS requirement can be satisfied in the new network, then there will be no problem. The problem arises if the new network cannot satisfy the QoS requirement. Do you terminate the session or continue it with lower quality? Although the latter will likely be chosen by most users, such decision can be preset by the user in his or her personal profile. Roaming agreements must exist in advance between the service providers in order for roaming to be allowed. The goal is to have a customer receive the same service (or as close to the same service) when travelling in an area supported by another network as the customer receives when in their home service provider's area. Authentication of the user in the home network and registration in the session manager must be done on a fly when a handoff also involves roaming. Otherwise, the transition from one network to another will not be smooth and may lose a connection or may experience a short outage in communication.

3.7 Customer Management

Customers have become very important in recent years as the telecom world has become very competitive with more service providers in business than ever before. All service providers try their best to keep their own customers and also to lure customers from other service providers by providing better service quality and also to offer incentives for leaving other service providers and joining them. A customer is a "king" these days in most of the developed countries in the world. Two subareas of customer management are required as part of customer management, namely subscription management and profile management.

3.7.1 Subscription Management

Subscription management is a feature that permits service providers to provision services for a specific subscriber . The feature is necessary to allow service providers to provision, control, monitor and bill the configuration of services that they offer to their subscribers. It focuses on the operations and management processes to manage subscription information. It is concerned with provisioning the subscription profile throughout all the systems and trading partners needed to realize the customer service. In 2G solutions the main repository of the subscription information is in the Home Locations Register (HLR). However, the management and administration interfaces for controlling this information is proprietary to each vendor. The use of proprietary interfaces is inconvenient for those service providers using multiple vendors' equipment since their provisioning systems have to accommodate multiple proprietary interfaces, which perform essentially identical functions. Moreover, it makes it more difficult to generate customer self care applications that allow subscribers to provision, and amend subscription data. The 4G environment requires more complex service delivery mechanisms than in 2G and 3G and subscription management is no longer simply an internal matter for a single operator but a capability that is achieved by linking together features across multiple service providers' operations support systems.

3.7.2 Profile Management

A customer profile is a customized, preference information that allows a personalized service by the service providers. The 4G network environment needs to focus more on customer profile management as a customer may access with different terminals depending on where they are and what they are doing. This will be more so than in 2G and 3G networks. The goal of profile management is to provide a ubiquitous, single look-and-feel access environment even in the presence of customers' multiple, heterogeneous terminals (e.g., mobile phone, PDA, laptop) and different operator networks. A customer must be able to change his profile from his terminal or from the Web for setting profiles for multiple terminal types. The customized or updated profile information must be propagated to all the systems in the network that maintain the information.

3.8 Terminal Management

Terminal management entails two subareas, namely terminal location management and terminal trace management. Terminal management exists in 3G networks and we believe this feature will continue to be needed but perhaps more important than before.

3.8.1 Location Management

The terminal location information can be used to make the QoS related decisions by the operations and management system when a user wishes to use a particular service and a certain set of QoS has been requested. It can be also used when a handoff is needed. It can also be used to provide a value-added service. Such a value-added service is currently provided in 2G and 3G networks for locating a missing or overdue child as well as locating "mis-behaving" spouse.

3.8.2 Terminal Trace Management

Terminal trace management is important for detecting and tracing stolen terminals or frauds, which are currently one of the biggest headaches experienced by the service providers today. There are many missing or stolen terminals in the world. When these terminals are illegally used by someone other than the owner, the terminal trace management feature can be used to trace the terminal. Terminals may not be stolen but the terminal IDs may have been copied and embedded into another terminal illegally. This feature can be used to trace such illegal use as well. Terminal trace management can also be used to measure performance between a terminal and a testing server within the network. This data is an additional source of information to the infrastructure performance monitoring and allows going further in monitoring and optimization operations. Traces can also play a key role in activities such as determination of the root cause of a malfunctioning terminal, advanced trouble shooting, optimization of resource usage and quality, RF coverage control and capacity improvement, and dropped call analysis.

4. Conclusion

This paper has examined the challenges and defined the requirements for operations and management of the 4G network environment. Although the 4G network has not yet been clearly defined, we have made some reasonable assumptions on the envisioned 4G network environment for specifying the requirements for the operations and management. That is, the 4G network environment will consist of previous 2G, 3G, WLAN, satellite networks and it will also likely consist of WiBro/WiMax, mesh networks, ad-hoc networks, and 4G networks. We plan to develop a detailed architecture for each of the required functional components also plan to apply the autonomic network management architecture we are currently developing to the operations and management of the 4G network environment.

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