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Performance of Next Generation Mobile Communication Systems

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Abstract: - The 4G is expected to be a quantum leap in Internet connection speeds capable of supporting real time multimedia traffic with throughputs of upto fifty times possible today. With today's 3G technology data rates are around 200 kbps (download) and 64 kbps (upload), which could go as high as 20 Mbps for 4G. This paper presents a 3G data traffic model with several traffic scenarios such as channels bursts in forward/reverse directions. The relative effect on CPU occupancy has been studied. The study highlights the relative processing requirements for different 3G data models that are expected to be valid for next generation mobile communication systems.

Key-Words: - 3G/4G systems, Third generation systems, Data traffic model, CPU occupancy

1 Introduction

The fourth generation wireless mobile systems, commonly known as 4G, are expected to provide global roaming across different types of wireless and mobile networks. 4G is an all IP-based mobile network using different radio access technologies providing seamless roaming and providing connection via always the best available network ([1]-[3]). 4G systems are expected to offer a speed of over 100 Mbps in stationary mode and an average of 20 Mbps for mobile stations reducing the download time of graphics and multimedia components by more than ten times compared to currently available 2 Mbps on 3G systems.

Currently, the 4G system is a research and development initiative based upon 3G, which is having trouble meeting its performance goals. However, the challenges for development of 4G systems depend upon the evolution of different underlying technologies, standards and deployment included in the third generation (3G) systems. This paper first presents an overall vision of the 4G features as an evolutionary step of 3G systems and discusses the evolutionary process from 2G to 4G in light of used technologies and business demands. Next, the results of a 3G simulation model are discussed and finally the expected advances in 4G systems are highlighted in terms of evaluated performance in the simulation model.

The first generation of mobile phones was analog systems that emerged in the early 1980s. The second generation of digital mobile phones appeared in 1990s along with the first digital mobile networks. During the second generation, the mobile telecommunications industry experienced exponential growth in terms of both subscribers and value-added services. Second generation networks allow limited data support in the range of 9.6 kbps to 19.2 kbps. Traditional phone networks are used mainly for voice transmission, and are essentially circuit-switched networks.

2.5G networks, such as General Packet Radio Service (GPRS), are an extension of 2G networks, in that they use circuit switching for voice and packet switching for data transmission resulting in its popularity since packet switching utilizes bandwidth much more efficiently. In this system, each user's packets compete for available bandwidth, and users are billed only for the amount of data transmitted.

3G networks were proposed to eliminate many problems faced by 2G and 2.5G networks, especially the low speeds and incompatible technologies such as Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) in different countries. Expectations for 3G included increased bandwidth; 128 Kbps for mobile stations, and 2 Mbps for fixed applications [4]. In theory, 3G should work over North American as well as European and Asian wireless air interfaces. In reality, the outlook for 3G is not very certain. Part of the problem is that network providers in Europe and North America currently maintain separate standards' bodies (3GPP for Europe and Asia; 3GPP2 for North America). The standards' bodies have not resolved the differences in air interface technologies. There is also a concern that in many countries 3G will never be deployed due to its cost and poor performance. Although it is possible that some of the weaknesses at physical layer will still exist in 4G systems, an integration of services at the upper layer is expected.

The evolution of mobile networks is strongly influenced by business challenges and the direction mobile system industry takes. It also relates to the radio access spectrum and the control restrictions over it that varies from country to country. However, as major technical advances are being standardized it becomes more complex for industry alone to choose a suitable evolutionary path. Many mobile system standards for Wide Area Networks (WANs) already exists including the popular ones such as Universal Mobile Telecommunications Systems (UMTS), CDMA, and CDMA-2000 (1X/3X). In addition there are evolving standards for Personal Area Networks (PANs), such as Bluetooth wireless, and for WLANs, such as IEEE 802.11.

The current trend in mobile systems is to support the high bit rate data services at the downlink via High Speed Downlink Packet Access (HSDPA). It provides a smooth evolutionary path for UMTS networks to higher data rates in the same way as Enhanced Data rates for Global Evolution (EDGE) do in Global Systems for Mobile communication (GSM). HSPDA uses shared channels that allow different users to access the channel resources in packet domain. It provides an efficient means to share spectrum that provides support for high data rate packet transport on the downlink, which is well adapted to urban environment and indoor applications. Initially, the peak data rates of 10 Mbps may be achieved using HSPDA. The next target is to reach 30 Mbps with the help of antenna array processing technologies followed by the enhancements in air interface design to allow even higher data rates.

Another recent development is a new framework for mobile networks that is expected to provide multimedia support ([5], [6]) for IP telecommunication services, called as IP Multimedia Subsystems (IMS) [7]. Real-time rich multimedia communication mixing telecommunication and data services could happen due to IMS in wireline broadband networks. However, mobile carriers cannot offer their customers the freedom to mix multimedia components (text, pictures, audio, voice, video) within one call. Today a two party voice call cannot be extended to a multi-party audio and video conference. IMS overcomes such limitations and makes these scenarios possible.

The future of mobile systems is largely dependent upon the development of 4G systems, multimedia networking, and upto some extent, photonic networks. It is expected that initially the 4G mobile systems will be developed and used independent from other technologies. With gradual growth of high speed data support to multimegabits per second, an integrations of services will happen. In addition, developments in photonic switching might allow mobile communication on a completely photonic network using Wavelength Division Multiplexing (WDM) on photonic switches and routers.

3G mobile offers access to broadband multimedia services, which is expected to become all IP based in future 4G systems ([8], [9]). However, current 3G networks are not based on IP; rather they are an evolution from existing 2G networks. Work is going on to provide 3G support and Quality of Service (QoS) in IP and mobility protocols. The situation gets more complex when we consider the WLAN research and when we expect it to become mobile. It is expected that WLANs will be installed in trains, trucks, and buildings. In addition, it may just be formed on an ad-hoc basis (like *ad-hoc networks* [10]-[11]) between random collections of devices that happen to come within radio range of one another.

In general, 4G architecture will include three basic areas of connectivity; PANs (such as Bluetooth), WANs (such as IEEE 802.11), and cellular connectivity. Under this umbrella, 4G will provide a wide range of mobile devices that support global roaming. Each device will be able to interact with Internet-based information that will be modified on the fly for the network being used by the device at that moment (Figure 1).

Most of the wireless companies are now looking forward to IPv6, because they will be able to introduce new services. The Japanese government is requiring all of Japan's ISPs to support IPv6 by 2006, when first 4G launch is expected. Although the US upgrade to IPv6 is less advanced, WLAN's advancement may provide a shortcut to 4G.

2 Performance Issues

A key controversy is emerging among the 4G developers about whether it will be an evolutionary or a revolutionary development. Some people believe that 4G will simply constitute an evolutionary technology (e.g., evolutions of WCDMA and cdma2000), that will emerge in ten years or so. Other group of people argues that since 3G development never delivered what it promised (like 2 Mbps performance), 4G development must accelerate. Users that are disappointed with 3G hope that 4G will yield revolutionary developments—not evolutionary ones. They hope that 4G deployments will occur on an accelerated timetable, rather than in ten years.

Regardless of the two approaches taken by developers it is important to understand the data model in 3G systems for a better understanding of data model in 4G systems. The CDMA 3G-1X High Speed Packet Data (HSPD) services feature provides a subscriber the ability to transmit bursts of data up to a raw speed of 153.6 Kpbs over a packet data network via the CDMA 3G-1X air interface. Prior to this feature, CDMA data services were limited to raw speeds of 9.6 Kpbs and 14.4 Kbps. The HSPD feature enables mobile users with laptop computers or other data devices conforming to the TIA/EIA/IS707A-1 standard to access various data applications, such as Internet Access, database Access, E-mail, File Transfer at higher speeds. These applications may reside on existing or custom designed data networks. The 3G-1X HSPD services are bi-directional and apply to both cellular and PCS systems.

- The CDMA 3G-1.25 MHz High Speed Packet Data Services (CDMA 3G-1X HSPD Services) feature allows mobile users to access data applications at a much faster rate, up to 16 times faster, than the current 2G Low Speed Packet Data Services (LSPD) data service feature available for CDMA. With the CDMA 3G-1X HSPD Services feature, a CDMA mobile user (with the appropriate mobile set that is compatible for 3G-1X HSPD) can access data applications, such as Internet access, Database access, E-mail, and file transfer at a higher speed.

- The CDMA 3G-1X HSPD Services feature is provided using data traffic over several channels. An active CDMA 3G-1X HSPD user always has an active signaling/traffic channel called the Fundamental Channel (FCH) running at 9.6 Kbps. A FCH does traffic transfer in the forward direction (F-FCH) and in the reverse direction (R-FCH). If an active 3G-1X HSPD user needs additional bandwidth, the 3G-1X HSPD mobile and the network undergo a burst negotiation and additional bandwidth is allocated. This additional bandwidth is handled by the Forward Supplemental Channel (F-SCH) and the Reverse Supplemental Channel (R-SCH) assigned to the call. Both the FCH and the SCH have a forward and a reverse direction. When the F-SCH is handling data bursts, the F-FCH does not transfer data traffic.

- The CDMA 3G-1X HSPD Services feature supports data calls having both forward and reverse discrete data bursts of 9.6, 19.2, 38.4, 76.8, and 153.6 Kbps in both directions over SCHs. The rate in one direction can be the same or different than the rate in the other direction. Therefore, the feature can support a maximum data rate of 153.6 Kbps in both the forward and the reverse directions. This compares to the LSPD rate of 9.6 Kbps in both the forward and the reverse directions simultaneously.

3. Third Generation System CPU Performance Model

3G radio access technologies are considered to be evolutions of 2G technologies that consist of IS-95 (cdmaOne), GSM and TDMA/IS-41 (based upon IS-136). The respective evolutions are called cdma2000, UMTS and UWC-136. International Telecommunications Union (ITU) facilitates 3G standards development via a subgroup called International Mobile Communications-2000 (IMT-2000).

The study presented in this paper deals with the traffic channel simulation as outlined in cdma2000 standard. Note that the 1X feature (not to be confused with the 2X, 4X, 8X and 16X data rates used later in this paper) means that the channel bandwidth is 1.25 MHz as opposed to future possibilities of 3, 6, 9 and 12 multiples of base channel bandwidth. Note also that the details of channel structure are not simulated here since the objective of the study was to get an estimate of CPU processing requirement in a hardware implementation. For instance, forward power control, pilot channel operation and details of Link Access Control (LAC), Medium Access Control (MAC), and call setup are ignored to simplify the model. Specifically, the simulation includes the

RC3 configurations of cdma2000 consisting of the following:

- Forward and reverse fundamental channels at 9.6 kbps
- Forward and reverse supplemental channels running at twice (2X), four times (4X), eight times (8X) and sixteen times (16X) the fundamental rate

The simulation setup uses a "data call model" that assumes simple data calls using the maximum data rates of the respective channels. For instance, model A in the first set of study assumes ten forward bursting channels operating at the full rate of 153.6 kbps, in addition to ten forward and ten reverse fundamental channels operating at 9.6 kbps. Four combinations of bursts have been simulated in the data call model. These burst combination are labeled as models A, B, C and D for notational convenience, as follows:

Model A: 10 forward bursts, 10 forward fundamental channels, 10 reverse fundamental channels

Model B: 10 reverse bursts, 10 forward fundamental channels, 10 reverse fundamental channels

Model C: 5 forward bursts, 5 reverse bursts, 10 forward fundamental channels, 10 reverse fundamental channels

Model D: No bursts, 10 forward fundamental channels, 10 reverse fundamental channels

Each model assumes a combination of handoff mechanisms, which are:

No handoff
2-way with no handoff in forward
3-way with no handoff in forward
Forward only, i.e. no handoff in reverse
2-way
3-way
6-way

Summary of assumptions in simulation are:

1. 20 simultaneous fundamental channels are used with 10 operating in each direction.
2. Variable number of bursts (0-10) at 16X is considered in each direction.
3. The frame processing times used are 0.08 msec and 0.12 msec per frame for forward bursting supplemental and fundamental channels, respectively, for the data call model. These delays for reverse direction are assumed to be 0.1 msec and 0.12 msec, respectively. The average frame delay due to soft handoff per call leg in the forward and reverse direction was assumed to be 0.02 msec and 0.07 msec, respectively.

Three data call models (models A-C) assume variable number of bursts in forward and reverse directions. The relative CPU occupancies for the three models are compared with the no burst occupancies (model D) in Figure 2. It is noted that the 6-way handoff results in the CPU occupancy of about 90% compared to approximately 80% occupancy in 3-way handoff. No handoff in either forward or reverse direction results in the occupancy of less than 70%.

4 Conclusion

A performance framework for the upcoming 4G system has been presented as an evolutionary step of 3G data model. The requirement, architecture and standards of 4G systems have been discussed. Next, a data simulation model of 3G systems has been developed. The results of the simulation model are presented that shows the effect on CPU occupancy under various data call scenarios and handoffs. The data call model shows various CPU occupancy results relative to no channel bursting for a 3G system. For instant, various combinations of 10 channel bursting, in addition to 10 forward and 10 reverse fundamental channels, with 3-way handoff may result in CPU occupancy of close to 80% compared to about 30% without any bursts.

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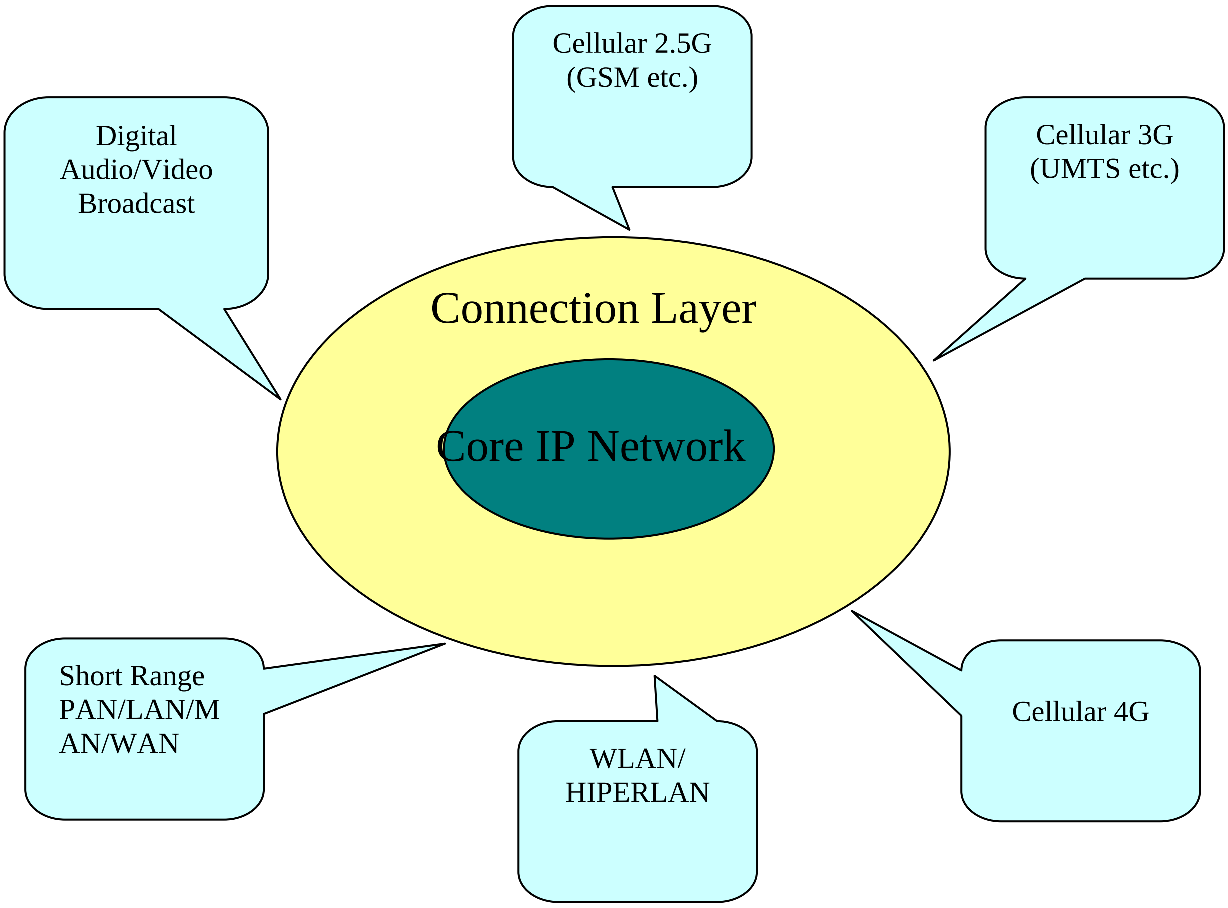

Figure 1: Seamless Connection of Networks in 4G

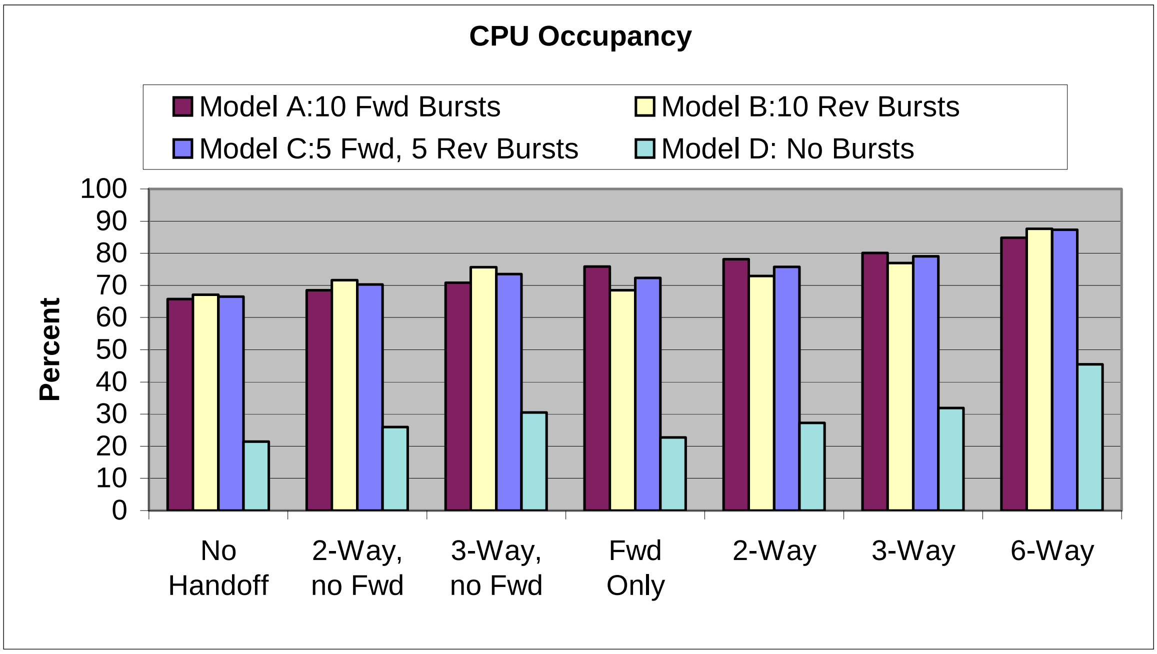
CPU Occupancy
Model A:10 Fwd Bursts
Model B:10 Rev Bursts
Model C:5 Fwd, 5 Rev Bursts
Model D: No Bursts
Percent
100
90
80
70
60
50
40
30
20
10
0
No Handoff
2-Way, no Fwd
3-Way, no Fwd
Fwd Only
2-Way
3-Way
6-Way

Figure 2