IPv6-based Beyond-3G Networking

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Abstract
This paper highlights the technical issues in IPv6-based Beyond-3G networking as a means to enable a seamless mobile Internet beyond simply wireless access to the Internet. Section 1 introduces Motorola Labs' vision of Beyond-3G systems. Section 2 describes the Beyond-3G network architecture. Section 3 discusses Beyond-3G networking technologies.

I. Introduction

Infrastructures for cellular systems have traditionally been based upon circuit-switched architectures. As wireless mobile systems transitions from 2G to 3G and beyond, packet-switched architectures based on IP technologies are being explored to more flexibly position these future cellular systems as major (and driving) components of the mobile Internet. At the same time, other wireless technologies such as wireless LAN (WLAN), wireless PAN (WPAN), DVB, and DAB are emerging as other means of wireless access to the Internet. However, it is the Beyond-3G concept, using enhanced IP networking technologies to integrate current and future radio systems (including 4G), that will enable a truly seamless mobile Internet beyond simply wireless access to the Internet.

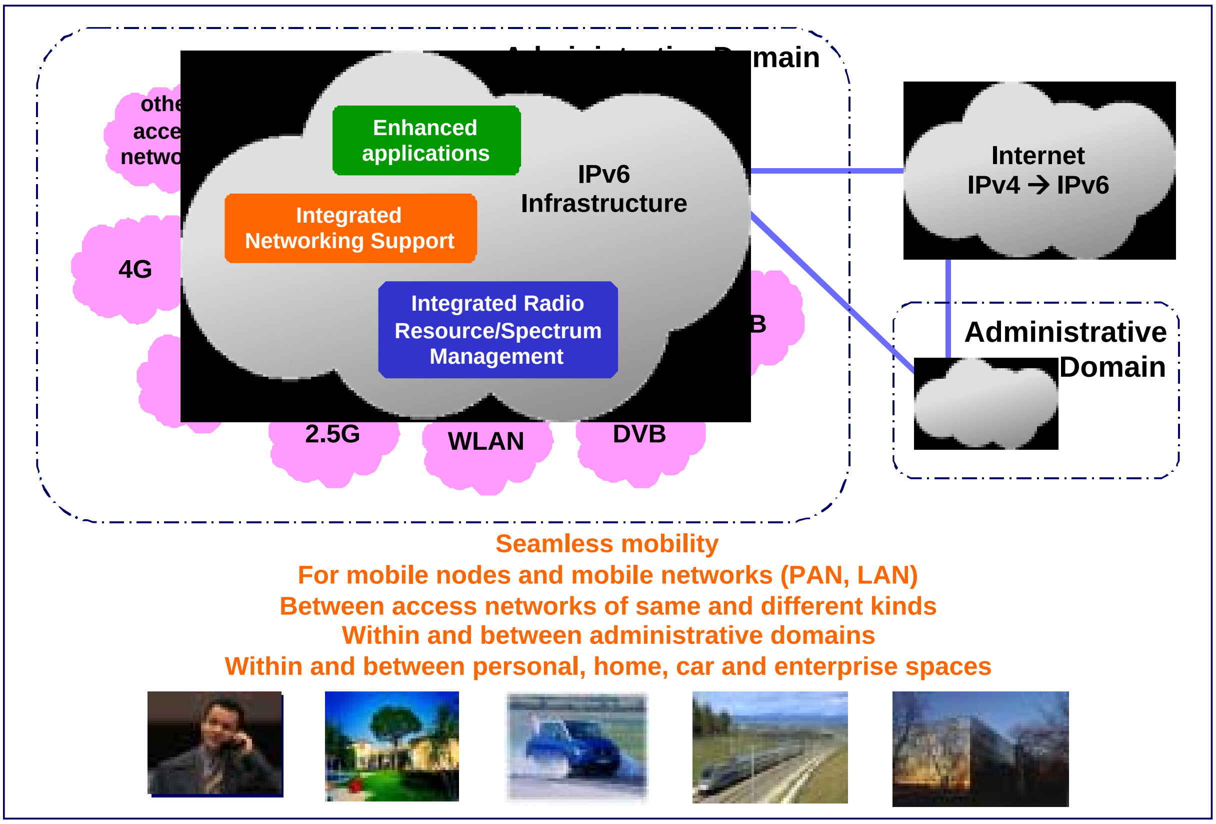

Figure 1: Motorola Labs' vision for Beyond-3G systems

Figure 1 illustrates Motorola Lab's vision for Beyond-3G systems, which is composed of 3 aspects: integrated networking support, integrated radio resource/spectrum management, and enhanced applications. Enabled by IP technologies as the foundation for integrated networking support, Beyond-3G systems provide advantages of allowing more flexible network designs to encompass heterogeneous wired and wireless technologies, more innovative applications, less expensive deployment, and faster technology adoption. Thus in Beyond-3G systems, opportunities are created for integrated management of scarce radio spectrum shared between them to more efficiently serve users' needs. There are also new opportunities for composite radio applications as well as location- and QoS-aware applications.

This paper focuses on the IP networking aspect of Beyond-3G systems, whose capability needs to be significantly enhanced to support mobility, end-to-end QoS, multicast and service provisioning for mobile users in both wired and wireless environments, to enable telecom-grade services for voice communications and broadcast-grade services for content streaming. Naturally, Beyond-3G networking is based on IPv6 due to its advantages with respect to address space, mobility, security and management. The AAA model serves as a foundation for administration of Beyond-3G systems. Mobile IPv6 needs to be extended to support fast and smooth handover between IP-subnets, to support mobility between radio networks of same and different types, within and between AAA administrative domains. Enhanced QoS policy framework and end-to-end QoS architecture capable of providing QoS support to mobile users are also required. Besides, QoS mechanisms need to adapt dynamically to particular link characteristics and support adaptive applications. With these enhancements, seamless mobility would then be provided to applications. As current standards do not yet fully uphold Beyond-3G networking requirements, Motorola Labs is committed to enhance existing standards and develop new ones in IETF as necessary. Besides internal research programs in Beyond-3G networking technologies, Motorola Labs is involved in the WINE GLASS and Moby Dick European projects to explore some of the Beyond-3G networking issues, developing testbeds and validating ideas.

II. Beyond-3G network architecture

This section describes the Beyond-3G network architecture.

II.1. IPv6-based administrative domain

The basic network architecture for a Beyond-3G system is as a set of AAA administrative domains interconnected by the Internet or some IP backbone. Such administrative domain is typically owned and administered by an organisation that can be an operator, an ISP, a content provider, a company, a university, etc.

An administrative domain is made of an IPv6 infrastructure, which may be composed of virtual elements thanks to VPN techniques. Depending on the requirements of the organisation, the IPv6 infrastructure in an administrative domain may incorporate various wired and wireless access networks, such as Ethernet, 802.11, W-CDMA, HiperLAN, etc. Enhanced IPv6 networking technologies are need to support seamless mobility for Beyond-3G mobile users:

- Authentication, Authorisation and Accounting (AAA) framework
- Mobility of mobile nodes and mobile networks (moving IP-subnets in LANs, PANs, etc)
- Fast (low delay) and smooth (low loss) handover
- Mobility between access networks of same and different kinds
- Mobility within and between administrative domains
- Mobility-enabled QoS policy framework
- End-to-end QoS architecture
- Mobility- and QoS-enabled multicast framework
- QoS-enabled transport protocols
- Plug-and-play network management
- Location-based communication and location information management
- IPv4-IPv6 interworking
- Enhanced networking APIs for QoS-, multicast- and location-aware applications
- etc

IPv6, the new version of the IP protocol, is of particular interest in Beyond-3G networking as it has been designed to solve the limitations of IPv4. One major issue for IPv4 is address space depletion. To allow billions and trillions of wireless mobile terminals to be always-on, as required by the revolution of mobile Internet, IPv6 is required to provide the necessary address space. Besides, IPv6 offers technical advantages over IPv4, including better support in packet processing, security, mobility and auto-configuration, that make it very suitable as foundation for Beyond-3G networking.

II.2. Cellular network architectures

Mobile telecommunications networks, such as 2G, 2.5G and 3G, define complete network architectures with specific Core Networks to incorporate mobility and QoS support. The users' demand for mobile access to the Internet and the operators' increasing preference to provide IP-based application services have suggested that it is both logical and beneficial that cellular network architectures evolve towards embracing a purely IP networking approach.

Thus, with Beyond-3G networking, radio access networks and base stations could be directly attached to the IPv6 infrastructure, without any traditional mobile-telecommunications Core Networks. This allows future radio network developments to concentrate on link-level mobility, QoS and radio resource management, leaving network-level mobility, QoS and network management to Beyond-3G networking.

III. Beyond-3G networking technologies

This section discusses some of the issues in Beyond-3G networking technologies.

III.1. AAA framework for secure administration of mobility, QoS and charging

AAA provides a secure administration framework essential for IP-based mobile communications. A mobile user has only access to, and is charged for, the services that his profile allows. Whenever a user moves into a foreign administrative domain, some kind of AAA signalling between the visited domain and the home domain is required to allow the visited domain to serve the user. Typically, the AAA server is in charge of first authenticating a user in an access network in an administrative domain, then authorising him to access some specific services with certain QoS characteristics, in accordance with his profile, and also maintaining billing data charging purposes. In the context of Beyond-3G networking, it is necessary to integrate AAA into mobility and QoS operations so that a mobile user can effectively enjoy continuous access to the Internet with the expected QoS support. Specifically, one primary challenge is to minimise its signalling overheads (especially with the AAA server) during mobility between access networks within and between administrative domains, without compromising with the security measures in authentication and authorisation.

III.2. IP mobility for seamless handover for mobile nodes and mobile networks (IP-subnets)

IP mobility support is primarily concerned with handover between IP-subnets for a mobile node, which has been addressed in Mobile IPv6. However, it is increasingly important that mobility of a leaf-set of one or more IP-subnets as a whole be supported as well, especially in the case of LANs inside moving vehicles and PANs on mobile users. Moreover, IP mobility has to co-operate with AAA mechanisms efficiently to allow secure mobility between access networks within and between administrative domains.

In all cases, IP mobility needs to be enhanced to exhibit the following characteristics:

- Low handover delay: In order to support realtime applications, the handover delay must be minimised between the moment when link layer connectivity to an access point in a new networks is established and the moment when the mobile node can effectively receive IP datagrams through the new access point.

- Low handover packet loss: In order to support loss-sensitive applications, switching point of attachment from one network to another must be accomplished with little or no loss of IP packets. Typical techniques involve make-before-break strategies and bicasting mechanisms.
- Efficient signalling: Even though the amount of available bandwidth is rapidly increasing, wireless bandwidth will remain a scarce resource. Another scare resource is the battery power available to a mobile node. The mobility support must therefore minimise the amount of (over-the-air) signalling and allow a mobile node to enter power-saving mode when it is not communicating.
- Scalable support: Proliferation of mobile devices and emergence of pico-cell architectures requires that mobility support is scalable for a large number of mobile nodes and mobile IP-subnets.

Seamless handover often refers to handover with low delay and low packet loss. As examples, the following approaches could help enhance Mobile IPv6 to support seamless handover:

- Early address configuration: When a mobile node enters a new IP-subnet it needs to obtain a topologically correct IP address (as its care-of address). This can be achieved through either stateful or stateless address allocation mechanisms. This step could add significant delay due to the effort needed to ensure that duplicate addresses are not used. Mechanisms such as sending advanced handover initiate messages to generate a new address in the new IP-subnet could reduce such delay.
- Reduced signalling path: A mobile node needs to update its home agent and its correspondent nodes every time it obtains a new care-of address. Frequent changes in this address can potentially cause significant disruption in traffic. In general, two mobility contexts according to network hierarchy can be identified, namely, macro-mobility and micro-mobility. Based on network hierarchy, macro-mobility management handles mobility between distant access points whereas micro-mobility is concerned with mobility between neighbouring access points. Using some hierarchical mobility support for local mobility management in micro-mobility could reduce the signalling delay.
- Reduced packet loss: When a mobile node changes its IP-subnet, packets transmitted to the old IP-subnet will be lost. Techniques such as small group single source multicast routing can be used to route packets to multiple locations thereby reducing packet loss.

Providing mobility support at the network layer has the advantages of being independent of the link layer used in network access. However, information from the link layer is essential for more effective and efficient support of seamless handover. For example, link-layer information could be used to predict the need for handover between access networks, and thus prepare handover at an optimal moment and condition.

III.3. IP QoS support in mobile networking

A QoS is typically based on intserv, diffserv, or a hybrid architecture of both. While intserv supports per-flow QoS, it suffers from concerns of scalability. On the other hand, diffserv is a more scalable approach but it supports only aggregated QoS. A hybrid architecture of both could offer the best of both worlds but it remains a challenge to support a end-to-end QoS architecture, which relies mainly on RSVP for end-to-end QoS signalling.

In a QoS architecture, a QoS policy framework could be established in which a QoS Manager serves as a Policy Decision Point (PDP) to co-ordinate resource allocation within a QoS domain, and access routers serve as Policy Enforcement Points (PEPs). In such framework, QoS requests transmitted through the network (e.g., using RSVP) are intercepted by the PEPs which then communicate with the PDP (e.g., using COPS) to determine how to honour these QoS requests. This concerns decisions in admission control, bandwidth allocation on a pre-flow basis, assignment to a diffserv BA, etc.

The provision and maintenance of QoS for mobile nodes adds even more challenge. Until now, IP technologies for QoS and mobility have been developed essentially independently, and little effort has been made to integrate their approaches. An established QoS session across the routers in a network needs to be maintained through a different path of routers as the node moves between different IP-subnets. This requires that QoS states, such as the diffserv BA assignment to the flow or the interserv bandwidth reservation, be re-negotiated and re-established by the QoS policy framework according to new constraints due to change in routing path. At the same time, the operation of QoS policy framework needs to be in accordance with seamless handover; otherwise, seamless mobility cannot be achieved for IP sessions with QoS requirements.

IP QoS architecture is independent of any specific access network. Thus, proper QoS mapping between IP QoS and access-network-specific QoS parameters is very important. Such mapping is indeed required between all protocol layers to eventually support an application's QoS requirement.

Multimedia applications are capable of being adaptive in its operations, for example by changing between coding techniques. This is a particularly valuable feature to be exploited when a mobile node traverses dissimilar access networks during the course of a session. Thus the application QoS interface and the QoS policy framework need to be enhanced accordingly.

III.4. Simple and reliable system deployment

In order to allow efficient and reliable deployment of a Beyond-3G system, access routers and access points (or base stations) need to be capable of both self-configuration and self-healing. When a new access router is added to an existing network, it should operate without manual configuration, possibly with the help of some network management server. When an element of the infrastructure fails, other elements should take up the function of the failed element. For example, when an access point fails, surrounding access points should detect the failure and increase their coverage to accommodate the affected users. While the failure would be reported to the system operator, users of the system should notice minimal disruption.

Beyond-3G systems must also accommodate the Internet's transition from IPv4 to IPv6. While a Beyond-3G administrative domain is based on IPv6, the wealth of content and services in the IPv4-based Internet must be available to Beyond-3G users. During the transition, there will effectively be two domains of IP networking capability. Although there are basic approaches addressing how to interconnect IPv4 and IPv6 networks, little work has been done with respect to AAA, mobility and QoS issues across the two domains. IPv4-IPv6 interworking technologies need to be developed to minimise adverse impact on the seamless mobility experience for Beyond-3G users when an IPv4 domain is involved in the users networking activities.

IV. Conclusion

This paper has introduced Motorola Labs' vision of Beyond-3G systems, described the Beyond-3G network architecture and discussed some major issues in Beyond-3G networking. The Beyond-3G vision is the means to achieve total mobile communications-Internet convergence to develop a seamless mobile Internet. This vision has placed enormous challenge on the evolution and enhancements of IPv6 networking technologies, which serve as the fundamental requirements in Beyond-3G systems. Plenty of research needs to be conducted in the coming years and Motorola Labs is committed to contribute actively in the development of the required Beyond-3G networking technologies.