Issues in Emerging 4G Wireless Networks

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Deployment of International Mobile Telephony 2000 standards for third-generation wireless networks may begin this year, with NTT DoCoMo planning to have a nationwide 3G network in Japan this year. These specifications give existing 1G and 2G operators the flexibility to evolve their networks, which support low-bit-rate data and are primarily designed for voice, into 3G systems. They also help satellite and terrestrial providers design new 3G systems.

Third-generation networks offer multimedia transmission, global roaming across a cellular or other single type of wireless network, and bit rates ranging from 384 Kbps to several Mbps. Analysts expect worldwide migration to 3G to continue through 2005, depending on market needs, carrier and operator incentives, recovery on investments in existing 1G and 2G wireless systems, and perceived threats to monopolistic wireless carriers in many countries.

4G WIRELESS NETWORKS

Meanwhile, researchers and vendors are expressing a growing interest in 4G wireless networks that support global roaming across multiple wireless and mobile networks—for example, from a cellular network to a satellite-based network to a high-bandwidth wireless LAN.

With this feature, users will have access to different services, increased coverage, the convenience of a single device, one bill with reduced total access cost, and more reliable wireless access even with the failure or loss of one or more networks. 4G networks will also feature IP interoperability for seamless mobile Internet access and bit rates of 50 Mbps or more.

Because deployment of 4G wireless technology is not expected until 2006 or even later, developers will hopefully have time to resolve issues involving multiple heterogeneous networks such as

- access,
- handoff,
- location coordination,
- resource coordination to add new users,
- support for multicasting,
- support for quality of service,
- wireless security and authentication,
- network failure and backup, and
- pricing and billing.

Network architectures will play a key role in implementing the features required to address these issues.

4G wireless networks support global roaming across multiple wireless and mobile networks.

POSSIBLE ARCHITECTURES

One of the most challenging problems facing deployment of 4G technology is how to access several different mobile and wireless networks. Figure 1 shows three possible architectures: using a multimode device, an overlay network, or a common access protocol.

Multimode devices

One configuration uses a single physical terminal with multiple interfaces to access services on different wireless networks. Early examples of this architecture include the existing Advanced Mobile Phone System/Code Division Multiple Access dual-function cell phone, Iridium's dual-function satellite-cell phone, and the emerging Global System for Mobile telecommunications/Digital Enhanced Cordless Terminal dual-mode cordless phone.

The multimode device architecture may improve call completion and expand effective coverage area. It should also provide reliable wireless coverage in case of network, link, or switch failure. The user, device, or network can initiate handoff between networks. The device itself incorporates most of the additional complexity without requiring wireless network modification or employing interworking devices. Each network can deploy a database that keeps track of user location, device capabilities, network conditions, and user preferences. The handling of quality-of-service (QoS) issues remains an open research question.

Overlay network

In this architecture, a user accesses an overlay network consisting of several universal access points. These UAPs in turn select a wireless network based on availability, QoS specifications, and user-defined choices. A UAP performs protocol and frequency translation, content adaptation, and QoS negotiation-renegotiation on behalf of users. The overlay network, rather than the user or device, performs handoffs as the user moves from one UAP to another. A UAP stores user, network, and device information, capabilities, and preferences. Because UAPs can keep track of the various resources a caller uses, this architecture supports single billing and subscription.

Common access protocol

This protocol becomes viable if wireless networks can support one or two standard access protocols. One possible solution, which will require interworking between different networks, uses wireless asynchronous transfer mode. To implement wireless ATM, every wireless network must allow transmission of ATM cells with additional headers or wireless ATM cells requiring changes in the wireless networks. One or more types of satellite-based networks might use one protocol while one or more terrestrial wireless networks use another protocol.

QUALITY OF SERVICE

Supporting QoS in 4G networks will be a major challenge due to varying bit rates, channel characteristics, bandwidth allocation, fault-tolerance levels, and handoff support among heterogeneous wireless networks. QoS support can occur at the packet, transaction, circuit, user, and network levels.

- *Packet-level QoS* applies to jitter, throughput, and error rate. Network resources such as buffer space and access protocol are likely influences.

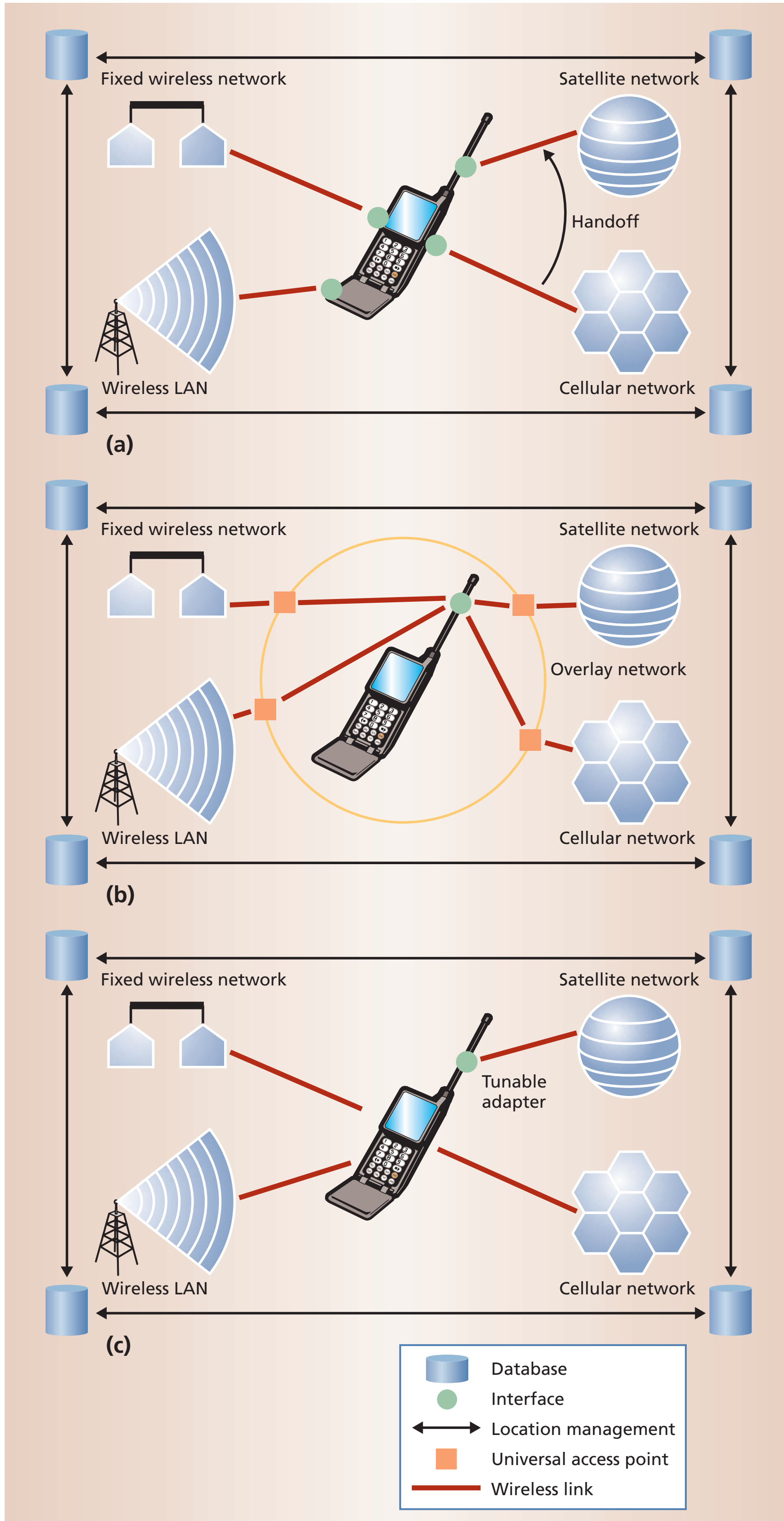

Figure 1. Possible 4G wireless network architectures. (a) A multimode device lets the user, device, or network initiate handoff between networks without the need for network modification or interworking devices. (b) An overlay network—consisting of several universal access points (UAPs) that store user, network, and device information—performs a handoff as the user moves from one UAP to another. (c) A device capable of automatically switching between networks is possible if wireless networks can support a common protocol to access a satellite-based network and another protocol for terrestrial networks.

- *Transaction-level QoS* describes both the time it takes to complete a transaction and the packet loss rate. Certain transactions may be time-sensitive, while others cannot tolerate any packet loss.
- *Circuit-level QoS* includes call blocking for new as well as existing calls. It depends primarily on a network's ability to establish and maintain the end-to-end circuit. Call routing and location management are two important circuit-level attributes.
- *User-level QoS* depends on user mobility and application type. The new location may not support the minimum QoS needed, even with adaptive applications.

Deploying a global QoS scheme may support the diverse requirements of users with different mobility patterns.

In a complete wireless solution, the end-to-end communication between two users will likely involve multiple wireless networks. Because QoS will vary across different networks, the QoS for such users will likely be the minimum level these networks support.

End-to-End QoS

Developers need to do much more work to address end-to-end QoS. They may need to modify many existing QoS schemes, including admission control, dynamic resource reservation, and QoS renegotiation to support 4G users' diverse QoS requirements. The overhead of implementing these QoS schemes at different levels requires careful evaluation.

A wireless network could make its current QoS information available to all other wireless networks in either a distributed or centralized fashion so they can effectively use the available network resources. Additionally, deploying a global QoS scheme may support the diverse requirements of users with different mobility patterns. The effect of implementing a single QoS scheme across the networks instead of relying on each network's QoS scheme requires study.

Handoff delay

Handoff delay poses another important QoS-related issue in 4G wireless networks. Although likely to be smaller in intranetwork handoffs, the delay can be problematic in internetwork handoffs because of authentication procedures that require message exchange, multiple-database accesses, and negotiation-renegotiation due to a significant difference between needed and available QoS.

During the handoff process, the user may experience a significant drop in QoS that will affect the performance of both upper-layer protocols and applications. Deploying a priority-based algorithm and using location-aware adaptive applications can reduce both handoff delay and QoS variability.

When there is a potential for considerable variation between senders' and receivers' device capabilities, deploying a receiver-specific filter in part of the network close to the source can effectively reduce the amount of traffic and processing, perhaps satisfying other users' QoS needs.

Although 4G wireless technology offers higher bit rates and the ability to roam across multiple heterogeneous wireless networks, several issues require further research and development. It is not clear if existing 1G and 2G providers would upgrade to 3G or wait for it to evolve into 4G, completely bypassing 3G. The answer probably lies in the perceived demand for 3G and the ongoing improvement in 2G networks to meet user demands until 4G arrives. ✷

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