♦ Dual Mode Service: Learning From Integrating an IP Multimedia Subsystem Service Into Existing Live Networks

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The IP Multimedia Subsystem (IMS) is an open, standards-based solution for delivering advanced communications services over IP networks. One such service is the dual mode service (DMS), that allows a subscriber to roam across multiple access networks, including Wi-Fi and macro-cellular, using a dual mode handset (DMH). In addition, fixed residential and enterprise numbers receive telephony services through Voice over Internet Protocol (VoIP). The service includes the ability to simultaneously ring multiple endpoints, ring them distinctively for different called numbers, and view logs of all calls. Several deployable architecture options are possible for building DMS, ranging from legacy, circuit switched network solutions through next-generation network solutions using an IMS architecture. Integrating new services and network elements is typically a time consuming and costly endeavor. In this paper, we report our experiences designing, integrating, and deploying a carrier-grade DMS based on an IMS architecture that overcomes many limitations found in other solutions. Our experience with DMS shows that cost and service development time is reduced by leveraging the IMS core's scalability, failover mechanisms, and service provisioning, rather than recreating all these mechanisms in service-specific platforms.

Introduction

Today's communications users are increasingly looking to technology to simplify their lives, increase their productivity, and optimize their limited economic resources. They look to integrated solutions on intuitive devices to simplify their work and family lives. They look for highly capable devices to extend workplace tools to any environment in an effort to squeeze as much productivity out of "idle" time as possible. And lastly, today's savvy communications users are demanding solutions that maximize the economic and performance characteristics of their location, regardless of whether they are at home, at work, or in between.

Service providers face similar challenges for simplification, increased productivity, and economic optimization. While wireless and wired service providers may be approaching the same subscriber solution space from opposite ends of the network, both are faced with increased competition, declining revenues, and increased network complexity issues.

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Panel 1. Abbreviations, Acronyms, and Terms

3G—Third Generation
3G-1X—CDMA2000 third generation
3GPP—3rd Generation Partnership Project
3GPP2—3rd Generation Partnership Project 2
AAA—Authentication, authorization, and accounting
AMR—Adaptive multi rate
AS—Application server
AuC—Authentication center
BR—Broadband router
B2BUA—Back-to-back user agents
BGCF—Breakout gateway control function
BSC—Base station controller
CAMEL—Customized Applications for Mobile Enhanced Logic
CDMA—Code division multiple access
CDMA2000—3G code division multiple access technology
CP—Communication platform
CSCF—Call session control function
DMH—Dual mode handset
DMS—Dual mode service
DSL—Digital signaling link
EV-DO—Evolution data only
GGSN—Gateway GPRS support node
GPRS—General packet radio service
GSM—Global System for Mobile Communication
HLR—Home location register
HSDPA—High-speed downlink packet access
HSS—Home subscriber server
ICE—Interactive connectivity establishment
IETF—Internet Engineering Task Force
IMS—IP Multimedia Subsystem
IN—Intelligent Network
IP—Internet Protocol
IPSec—IP security
ISC—IMS Service Control
ISDN—Integrated Services Digital Network
LAN—Local area network
LDAP—Lightweight Directory Access Protocol
MGCF—Media gateway control function
MGW—Media gateway
MMS—Multimedia messaging service
MRFC—Media resource function controller
MSC—Mobile switching center
NAPT—Network address port translation
NAT—Network address translator
OAM&P—Operations, administration, maintenance, and provisioning
PC—Personal computer
PDA—Personal digital assistant
PLMN—Public land mobile network
POTS—Plain old telephone service
PSTN—Public switched telephone network
QoS—Quality of service
RAN—Radio access network
RBGW—Residential broadband gateway
RTP—Real Time Transport Protocol
SDP—Session Description Protocol
SEG—Security Gateway
SGSN—Serving GPRS support node
SIP—Session Initiation Protocol
SMS—Short message service
SOHO—Small office home office
SPC—Stored program control
SQL—Structured query language
STUN—Simple Traversal of UDP through NATs
TCP—Transmission Control Protocol
TDM—Time division multiple
UMTS—Universal Mobile Telecommunications System
UDP—User Datagram Protocol
UMA—Unlicensed mobile access
UNC—UMA network controller
VCC—Voice call continuity
VLR—Visitor location register
VoIP—Voice over IP
WAN—Wireless area network
WCDMA—Wideband CDMA
Wi-Fi—Wireless Fidelity, an implementation of the IEEE 802.11 standard
WLAN—Wireless local area network
xxSN—Generic switching node

A "win-win" solution for service providers and subscribers is a highly integrated, flexible, and efficient network solution that allows users to communicate efficiently, productively, and in a highly integrated manner regardless of their location or method of access. Alcatel-Lucent's dual mode service (DMS) is one converged communications services solution leveraging the strengths and flexibility offered by a standards-based IP Multimedia Subsystem (IMS) service solution [1, 2, 3, 5]. DMS allows a subscriber to seamlessly access services while moving between Wi-Fi and cellular networks using a dual mode handset (DMH) [10, 23]. Additionally, the cellular number can be associated with fixed residential and enterprise numbers that receive telephony services through VoIP, providing highly integrated and convenient subscriber services. DMS offers service providers cost optimization through the efficient use of network resources by offloading traffic from cellular networks to the Wi-Fi environment and wireline broadband networks where the cost of transport is typically lower.

Several architectural solutions are possible for deploying and designing a DMS solution [8, 16, 17, 23]. In this paper, we compare deployment alternatives in terms of impact to operator legacy cellular time division multiplexing (TDM) and IP networks, efficiency of voice routing, and end-user feature consistency across user locations. Some solutions require service providers to continue investing in the legacy, circuit switched network and do not leverage next generation networks using Session Initiation Protocol (SIP) [20] and a full IMS architecture [1, 2, 3]. This is a limiting factor when considering network evolution. In addition, integrating new services and network elements is typically time consuming and costly and would need to be rapidly amortized if the solution does not provide a good evolutionary fit.

In this paper, we report on our experience designing, integrating, and deploying a carrier-grade DMS based on an IMS architecture that overcomes limitations in other solutions. The cost and service development time is reduced by leveraging the IMS core's scalability, failover mechanisms, and service provisioning, rather than recreating all these mechanisms in service-specific platforms. Our initial experience with this solution shows that building on the IMS network and its complete service management capabilities reduces the service lifecycle cost and provides a long-term standard solution.

The paper is organized as follows: We first provide an overview of the DMS solution. Next, we compare the architectural options for deploying and building a DMS solution, highlight our chosen implementation, and examine the benefits of deploying an IMS-based DMS solution. We follow with a discussion demonstrating the integration challenges of building DMS and summarizing several trial and commercial DMS deployment experiences. We provide several insights into Alcatel-Lucent's method of solution management, and conclude with our thoughts and observations on future evolution.

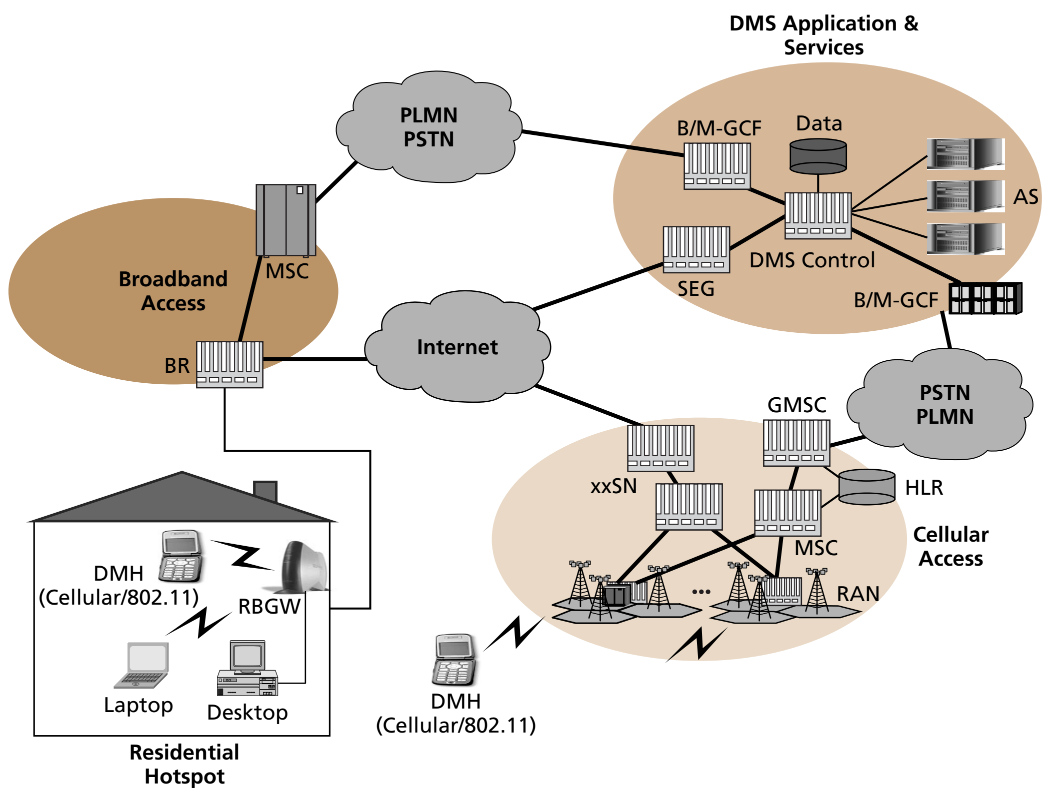
DMS Solution Overview

The Internet Protocol (IP) Multimedia Subsystem (IMS) is an open, standards-based solution for delivering advanced communications services over IP networks. IMS is an internationally recognized standard defined by the 3rd Generation Partnership Project (3GPP*/3GPP2) [1, 2, 3, 5]. The IMS standard supports access from many common broadband networks including Global System for Mobile Communications* (GSM*), wideband code division multiple access (WCDMA), CDMA2000* [6], Ethernet, and Wi-Fi. IMS provides the ability to integrate voice, video, and data services that bring new value to end-users and service providers [9]. IMS-based services support person-to-person and person-to-content communications in a variety of modes—including voice, text, pictures and video, or any combination of these—in a highly personalized and controlled way.

Service providers want to introduce compelling new services that generate revenue quickly—starting with seamless voice convergence [10]. Seamless voice convergence has gained a lot of momentum in the service provider industry and represents one of the first steps in realizing true fixed-mobile convergence. One such service based on the IMS architecture is the dual mode service (DMS), which allows a subscriber to seamlessly move between Wi-Fi and cellular access networks using a dual mode handset (DMH) or equivalent device.

DMS offers subscribers a rich set of end-user features and capabilities including a DMH device that works in both Wi-Fi and cellular domains that can exploit the same mobile feature set (e.g., voice, data, short message service [SMS], voicemail), while roaming between Wi-Fi and cellular networks. Dual mode service also provides a web communication portal for managing features and viewing logs of calls. The DMH is a powerful tool in providing a single "contact me" number that leverages the efficiencies of the access network while maintaining constant connectivity and reachability. In addition to the services assigned to the cellular number or "personal number," a DMS service may associate and integrate services between two types of numbers, the personal number and the residential or "family number." For small office home office (SOHO) or small enterprise subscribers, the family number may be a team number that represents a workgroup or common function. Family numbers are associated with fixed plain old telephone service (POTS) phones and/or SIP softclients on other single mode endpoints such as personal digital assistants (PDAs), personal computers (PCs), and laptops within a residence that are typically shared amongst the family participating in the service. The combination of these numbers offers the capability of coordinating call delivery between a residential primary phone number and individual mobile phone numbers for family members. For example, incoming calls to the family number may optionally simultaneously ring the DMH and fixed endpoints and ring them distinctively for different called numbers. This will enhance lifestyle convenience and address the need for family reachability.

Figure 1 illustrates a generic IMS-based DMS solution architecture, where the IMS network provides the seamless inter-working between wired and wireless environments. Within the DMS residential hotspot, a



AS—Application server
B-GCF—Breakout gateway control function
BR—Broadband router
DMH—Dual mode handset
DMS—Dual mode service
GMSC—Gateway mobile switching center
HLR—Home location register
M-GCF—Media gateway control function
MSC—Mobile switching center
PLMN—Public land mobile network
PSTN—Public switched telecommunications network
RAN—Radio access network
RBGW—Residential broadband gateway
SEG—Security gateway
xxSN—xx Serving/support node

Figure 1.
Dual mode service solution from end-user and operator perspective.

residential broadband gateway (RBGW) provides the functions of a wireless local area network (WLAN) access point, Ethernet router, and broadband gateway. The RBGW also provides SIP user agent functions for POTS phones connected via RJ-11. DMS endpoints access DMS network services through the RBGW and the asynchronous digital subscriber line (ADSL), cable or broadband IP network while they are in the coverage area of the RBGW. The DMS subscriber may enter and/or leave the RBGW coverage area and will use the optimal or preferred access technology based on heuristic intelligence and preferences defined on the dual mode handset. When DMS subscribers are outside the RBGW coverage area, they access DMS services via the cellular network. The DMS network solution is shown decomposed into five typical subsystems: control, dBase, application logic, media gateway, and security gateway. For scalability and routing efficiency, the dBase, media gateway, or security gateway functions may be geographically distributed. While the diagram illustrates the DMS network as a separate network entity, it is generally deployed by the broadband or cellular operator. However, it may also be deployed by a third party provider.

Alcatel-Lucent's DMS provides a consistent and optimal communications service experience to subscribers regardless of whether they are located in their home, in their office, on the road, or moving among all three. Communication is the key to personal and business success, and DMS facilitates consistent voice, video, and data communications by leveraging IMS. Because IMS is access agnostic and supports circuit-to-packet inter-working, DMS subscribers are able to continue communicating via voice, video, or data while seamlessly and flexibly moving among cellular, Wi-Fi, and wired access environments.

Seamless communication is a key element of Alcatel-Lucent's DMS, but it is only one of several complementary elements of the service. Consistent and integrated services, devices, and subscriber management controls provide other key elements in the full-featured solution. Alcatel-Lucent continues to pursue a very proactive approach in bringing essential DMS components to market through extensive partnering.

DMS subscribers enjoy access to consistent and highly integrated services. In addition to high quality voice services in cellular and IP access environments, the DMS also provides access to integrated voicemail, call logs, and DMS feature management controls, regardless of whether subscribers are accessing the service from their DMS handset, through a DMS compliant client on their PDA, or through the DMS subscriber portal from their home or office PC. Alcatel-Lucent has worked with many device and applications providers to ensure that a consistent and optimal DMS experience is achieved given inherent device limitations.

To help illustrate the integrated nature of DMS in cellular and home coverage areas, we will briefly describe how seamless access, highly integrated with intelligent value-added services, is leveraged by a few key DMS features: simultaneous ring, distinctive tones, and sequential ringing. As a DMS subscriber moves in and out of the home, voice calls made to the family number will ring home phones as well as DMS endpoints and may, optionally, simultaneously ring the cellular-based DMS handset. Any home POTS phone, DMS endpoint, or DMS handset is able to answer the call; as a result all other endpoints no longer ring. A complementary simultaneous ring feature allows the home phones to simultaneously ring when calls are made to the cellular number while the DMS handset is the coverage area of the RBGW. In this case, a distinctive tone is sounded on the DMS endpoints to help identify whether the call was to the cellular number or the family number. This capability allows parents to let their teen answer his or her own calls and vice versa. The sequential ring, or follow-me capability, allows calls to either the cellular number or home number to sequentially ring a list of numbers until the call is answered or directed to the appropriate voicemail. A subscriber portal provides access to call feature management for simultaneous ring, distinctive tones, sequential ring, call forwarding, as well as access to call logs and voicemail from any DMS endpoint per device limitations.

Alcatel-Lucent's IMS-based DMS solution provides a complete communications solution for subscribers that spans the home, office, and places in between with a consistent and highly personalized communications experience. The remaining sections of this paper will further discuss and contrast alternative solutions and discuss insights gained through deployment experience.

Architecture Approaches

The key challenge for a fixed-mobile convergence solution is to provide call services over Wi-Fi connected to a subscriber's or third party's broadband IP connection, when available, and transparently fall back to wide area cellular voice and data coverage when the user is elsewhere. In this section we define and review four architectural approaches and compare them along three dimensions:

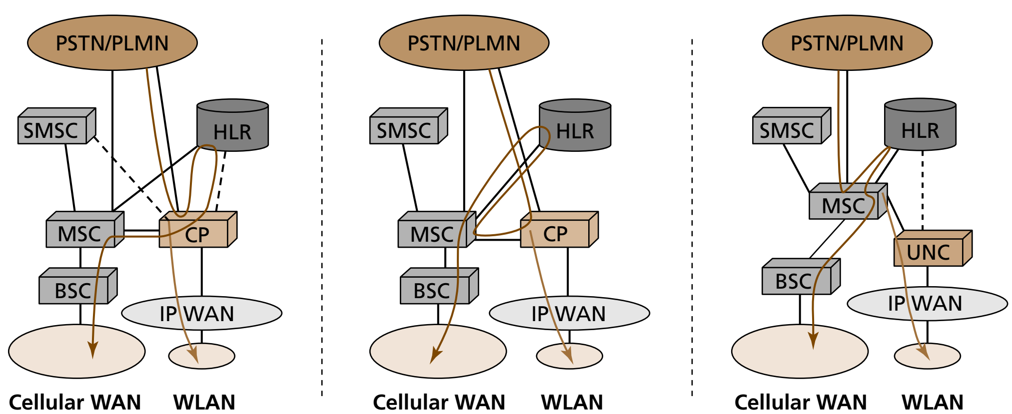
- Required connectivity to operator legacy cellular, TDM, and IP networks,
- Efficiency of circuit voice routing, and
- Feature transparency between cellular and Wi-Fi.

MSC Emulation

Figure 2 shows a variety of architecture approaches. In the MSC emulation architecture approach shown in Figure 2a, the HLR is used to track the location of the subscriber. Whenever the user enters Wi-Fi coverage, the HLR is updated with a pseudo-MSC address. For terminating calls, the HLR is queried and the call is sent to whatever MSC or pseudo-MSC the user last registered from. Support for SMS, customized applications for mobile enhanced logic/intelligent network (CAMEL/IN), and supplementary services are straightforward, as they replicate what is done in an MSC. If the gateway MSC functions also are emulated, all terminating calls must be force-routed into the emulating system. The advantage of this variant is the ability to control call handling both when the user is in cellular coverage and when the device is switched off.

Voice Call Continuity

The approach based on voice call continuity (VCC) is being defined in [4, 7] and uses the same basic network diagram as the MSC emulation approach (Figure 2a). Terminating calls are force-routed into the DMS system, which acts as a gateway MSC, but with operator and subscriber configurable logic for determining in which domain—cellular or Wi-Fi—call delivery is first attempted. The approach permits the handset to be simultaneously registered in the



(a) MSC emulation/voice call continuity. **(b)** 2-number solution. **(c)** Unified mobile access.

BSC—Base station controller
CP—Control processor
HLR—Home location register
IP—Internet Protocol
MSC—Mobile switching center
PLMN—Public land mobile network
PSTN—Public switched telecommunications network
SMSC—Short message service center
UMA—Unlicensed mobile access
UNC—UMA network controller
WAN—Wide area network
WLAN—Wireless local area network

Figure 2.
Architectural approaches.

cellular network while receiving calls in Wi-Fi. This results in several benefits, including bi-directional handover, faster handover (no delay in performing GSM registration), and better support for coverage dead spots, but requires the system to track and internally store when the user is in Wi-Fi mode, versus when the user has IP connectivity through the cellular network. Support for all legacy services such as SMS and CAMEL/IN is possible, but requires additional service logic, since the HLR no longer has complete knowledge of the subscriber's location.

Two Number

The third approach is a category we call two number-based solutions [8, 16], applicable to both operator and enterprise hosted equipment, shown in Figure 2b. It only requires a loose integration with the wireless infrastructure. As opposed to the other approaches, each subscriber has two numbers, a primary and a cellular number. The subscriber publicizes the primary number. Terminating calls to the primary number are routed directly to the system, which attempts to deliver the call in Wi-Fi. If call delivery fails, the stored cellular number is retrieved and used to re-attempt delivery in the cellular network. Calls originating in the cellular network can be forced back through the system (to replace the cellular number with the primary number as caller ID) or can go direct (where caller ID will vary). Calls to the cellular number are discouraged, since they cannot be delivered to Wi-Fi and are typically delivered at a higher cost. Support for SMS, CAMEL/IN, and a mid-call supplementary service is very challenging because of the dual numbers. Nevertheless, the wireline operators and enterprises that favor this approach may not require full support for these wireless services.

Unlicensed Mobile Access

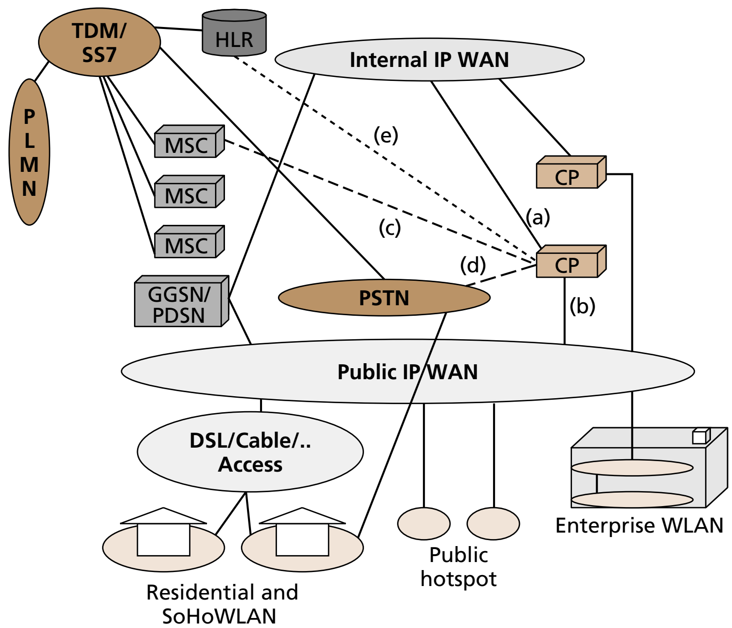
In the unlicensed mobile access (UMA) [16, 17, 23] approach shown in Figure 2c, wireless GSM operators can leverage their existing circuit and packet core network to extend GSM services while a handset is in range of a Wi-Fi or Bluetooth* access point. A new network element, called the UMA network controller (UNC), emulates the GSM base station controller (BSC) interfaces towards the MSC and serving gateway support node (SGSN). The interface to the handset is an IPsec tunnel [15] over which packetized voice, GSM signaling, and non-voice data are sent. At the GSM radio network layer, the UMA overlay "cell" created by the wireless access points is added to the neighbor cell list for each GSM cell. Voice features are provided by the existing MSC, which constrains operators' ability to quickly develop new services. Seamless data handover is provided by tunneling subscriber non-voice traffic to the gateway GPRS support node (GGSN), even when in Wi-Fi.

Having described the four architectural approaches, we will now compare and summarize the approaches along three dimensions: connectivity to legacy networks, efficiency of circuit voice routing, and feature transparency between cellular and Wi-Fi.

Connectivity to Legacy Network

A generic network architecture for the Dual Mode Service is shown in **Figure 3**. The communication platform (CP) represents an instance of the implemented system. Five potential integration interfaces are shown. Interface (a) and interface (b) represent the signaling and media bearer interfaces to internal and public IP wide area networks, respectively, and are used by all four architectural approaches. The internal WAN is used to pass traffic between distributed elements of the CP, e.g., between media gateways and to security gateways. For UMA, it is also used for tunneling user data to the GGSN.

Interface (c) represents the logical connection for signaling (through the SS7 network) and TDM voice trunks to MSCs. For the MSC emulation and VCC approaches, all PSTN and public land mobile network (PLMN) calls to a DMS subscriber must traverse trunks to a MGW that is controlled by the DMS control function. If the cellular network is serving the subscriber, the call hairpins back out to the cellular network MSCs. If an operator's MSCs support media gateway virtualization [12], transcode free operation, or an onboard media gateway controller, this traffic can alternatively be sent over interface (a). For UMA, each UNC has a circuit-based A-interface to its mated MSC. IP-based approaches may also be possible if the operator's network supports transcoder-free operation. The UNC must additionally have direct voice handover trunks to each GSM MSC within the region



CP—Control processor
DSL—Digital subscriber line
GGSN—Gateway GPRS support node
GPRS—General packet radio service
HLR—Home location register
IP—Internet Protocol
MSC—Mobile switching center
PDSN—Packet data serving node
PLMN—Public land mobile network
PSTN—Public switched telecommunications network
SoHo—Small office home office
SS7—Signaling System #7
TDM—Time division multiplexing
WAN—Wide area network
WLAN—Wireless local area network

Figure 3.
Generic network architecture showing dual mode service communication platform connectivity.

the UNC serves. Creating such handover trunks requires a lot of work for network operations personnel and the trunks need to be correctly re-sized as traffic increases. This bounds the geographical area that a single UNC can practically serve, but may not be an issue for smaller operators with few MSC locations.

Interface (d) is a direct interface to the PSTN and is optional. In its absence, all PSTN traffic is tandemed through the MSCs. For the two number solution approach, PSTN-originated traffic (to the primary number) arrives here, permitting a bypass of the MSCs. For the MSC emulation and VCC approaches, the interface is used for terminating PSTN calls. In order to use it for PSTN originated calls, coordination is required, as it entails cellular to PSTN portability of individual numbers while retaining correct handling within the operator's own network.

Finally, interface (e) is an interface to the home location register (HLR) and/or authentication, authorization, and accounting (AAA) server. The interface may be used for subscriber access authentication against operator-stored credentials, for determining the subscriber location on the cellular network, and, potentially, for retrieving subscriber feature data. The operator's existing HLR/authentication center (AuC) or AAA typically authenticates residential subscribers.

Efficiency of Circuit Voice Routing

In order to support bi-directional handover with the emulated MSC, VCC and 2-number solutions, calls originating and terminating in cellular must be forced through the DMS system, such that there is an anchor point for potential future handovers. For terminating calls this can be accomplished by using number portability (several approaches are described in [11]), CAMEL/IN triggers, or by issuing new numbers homed to the DMS system. For originating calls, CAMEL/IN triggers are required. Circuit voice must now be backhauled to the closest media gateway controlled by the DMS system, which adds expense. Adding more media gateways minimizes trunking distance and allows use of VoIP between media gateways and thus longer-term operational cost savings.

UMA can make use of all the circuit routing optimization that is available in GSM, including optimal routing and transcoder-free operation. As UMA traffic increases in Wi-Fi, the operator must continue to add circuit switching capacity to the cellular network infrastructure. If the operator centralizes the UMA-based design, and only uses a few high capacity UNCs, long distance TDM trunking is required. Distributing the UNC, potentially down to one per MSC, impacts more in-service switches and increases the total amount of hardware required to support local traffic peaks and redundancy.

Feature Transparency Between Cellular and Wi-Fi

In the MSC emulation approach, the DMS system emulates a visited MSC and thus receives a copy of the subscriber's feature setting, enabling it to provide identical service in Wi-Fi. A method must be provided for the subscriber to change feature settings such that they are reflected back in the HLR. It is also possible to provide a different or expanded set of services, such as simultaneous ringing or enterprise features, while in Wi-Fi, in which case, subscriber specific service data need to be stored in the communication platform dBase. The VCC approach has similar flexibility. The two number approach does not achieve feature transparency, since HLR service data are not available while the subscriber is in Wi-Fi; e.g., call barring and unconditional call forwarding features must be dual provisioned. Services such as SMS, multimedia messaging service (MMS), and calling name display pose particular challenges, as only the cellular number is involved in certain usage scenarios. UMA achieves feature transparency by reusing GSM signaling between the handset and UNC. Handset client redesign is minimized and both voice and data services work identically in GSM and in Wi-Fi/Bluetooth networks. All subscriber data are housed in the HLR and service logic is always executed in the serving MSC.

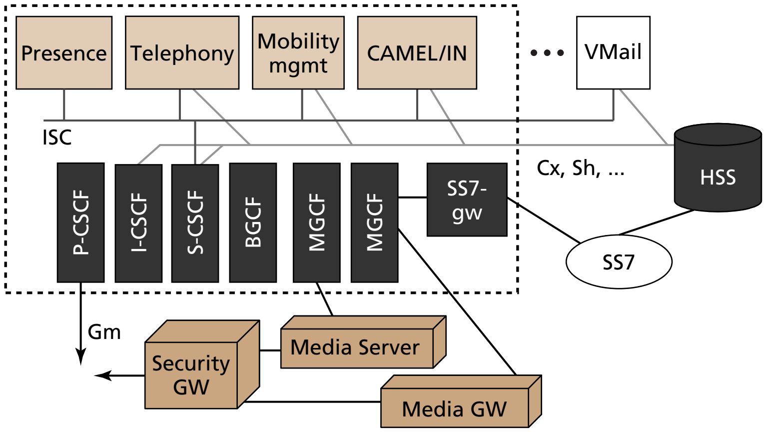
In the next section we describe our IMS-based Dual Mode Service solution that can be configured to support each of the first three architectural approaches described.

Benefits of Building on IMS

IMS is an architecture that presumes IP networks are widespread and capitalizes on their strengths. By building on the layering concepts inherent in IP networking, IMS focuses on providing enhanced communication services that allow content to be exchanged between endpoints without being constrained by lower level details. Doing so allows IMS to provide:

- Functional partitioning with standard interfaces,
- Access network independence,
- Support for multiple bearer types, and
- Endpoint location independence.

In **Figure 4** we show our IMS-based Dual Mode Service solution. Media processing is performed by the media gateway, media server,m and the optional security gateway/packet data gateway. The call session control functions (CSCFs), along with the breakout gateway control function (BGCF), media resource function controller (MRFC), media gateway control function (MGCF), and signaling gateway, form the heart of the IMS control plane. Subscriber data that are shared between applications are stored in the home subscriber server (HSS), or can be split between legacy HLRs and the HSS. Service logic is provided by application server functions such as the presence server, telephony feature server, CAMEL/IN features, and voicemail. These application functions interface to the serving-CSCF through the standardized IMS service control (ISC) interface and to the HSS through the Sh or other dBase query interface such as Lightweight Directory Access Protocol (LDAP) or structured query language (SQL). As we will see later, the standardized application interfaces provide several benefits from both a development and service lifecycle management perspective.



Cx—Interface
BGCF—Breakout gateway control function
CAMEL—Customized Applications for Mobility Enhanced Logic
CSCF—Call session control function
Gm—Interface
GW—Gateway
HSS—Home subscriber server
I-CSCF—Interrogating CSCF
IMS—IP Multimedia Subsystem
IN—Intelligent network
IP—Internet Protocol
ISC—Interface
MGCF—Media gateway control function
P-CSCF—Proxy CSCF
S-CSCF—Serving CSCF
Sh—Interface
SS7—Signaling System 7

Figure 4.
Functional decomposition of Alcatel-Lucent's IMS-based dual mode service solution.

Although the 3GPP/3GPP2 decomposition with standardized interfaces between various functions may seem complex to manage, this does not need to be the case. Indeed, the Alcatel-Lucent control platform provides operators a single product platform that can concurrently host all but one of the functions shown in the dashed box. Additional functions for quality of service, security, MSC-emulation, emergency call handling, legal intercept, etc., are also available. Naturally, operators have the option of distributing these functions across multiple physical network elements, either multiple control platforms or third party platforms, to accommodate operational requirements, inclusion of third party innovative service extensions, or other preferences.

Functional Partitioning With Standard Interfaces

One area where the IMS architecture moves beyond other solutions is in the explicit partitioning of the many functions needed to provide telecommunications services into realizable units, together with the use of industry standards for the interfaces between these units. This partitioning has been done both vertically (access/resource layer, session management layer, and services layer) as well as horizontally (e.g., authentication/authorization servers, routing servers, session servers, service provisioning).

This means that functions common to multiple applications can be implemented once in the core of the system and then reused by those applications running on that core. This reuse is possible even if the applications do not operate on the same set of media. For example, authentication, authorization, and accounting (AAA) form one such set of capabilities commonly required by applications. With IMS, a service provider may use a single AAA function (in the HSS) to provide these capabilities to an application controlling broadcast video streams, as well as to an application controlling switched voice calls. Standardized mechanisms for subscriber service provisioning (through HSS filter criteria) are another IMS system benefit that reduces service lifecycle cost.

This reuse of core functionality across applications also means that new applications can be easily grown onto an IMS that has been deployed for other purposes. For example, Alcatel-Lucent's DMS solution described in this paper is being added to IMS installations in the field that were first deployed to provide video and data service.

Key to being able to grow DMS onto an existing system is the IMS service control interface, which allows application servers to be developed in a way such that they can "plug into" the IMS core. This means that Alcatel-Lucent can use internally developed application servers (such as a mobility management server) and servers provided by third party vendors (such as a telephony feature server or a gaming server) to provide the exact mix of features required by the service provider. All of these servers use the ISC interface to access the common functionality provided by the core components of IMS.

Another strength of this partitioning is that it allows IMS to scale more effectively than earlier, more monolithic architectures. In earlier architectures, different types of capacities such as computational, access support, and bearer switching were coupled. When system growth was required to address limitations in one area—such as computational capacity—this forced growth in the coupled areas as well, even if those areas were not yet at capacity.

Access Network Independence

Some of the earlier generation of stored program control (SPC) switches such as the 5ESS® switch had begun to abstract the concept of an access network. Many softswitches have extended this approach and allow their services to be applied to an even wider variety of endpoints. This can also be further enabled by the choice of the SIP protocol as the basis for a common lingua franca used to interface to all endpoints.

IMS continues in this vein and has refined the concept of the access network so that any given service can be applied to an endpoint without regard to whether that endpoint is found on a wireline access network, a traditional cellular network such as GSM/UMTS or CDMA, or a Wi-Fi access network. With DMS, the same set of services can be applied to one endpoint even as that endpoint roams between access networks.

Support for Multiple Bearer Types

IMS also continues the direction taken in softswitches of separating the service logic from the specifics of the bearer stream being switched. A given IMS service, e.g., a redirection service such as call forwarding unconditional, can be applied to a voice session whether that voice is encoded with G.711, AMR, or G.726. That same service can also be applied to a session dealing with video-stream-encoded voice traffic. Indeed, it can also be applied to a session with multiple bearer streams. This means that while an operator may initially deploy the Alcatel-Lucent IMS system to handle voice bearer streams, it has an evolution path that can support adding richer features such as video or multimedia bearers when needed.

Location Independence

Building on IP-based transport networks gives IMS two additional benefits. First it allows for home service control. This means that a "home" service instance can control an endpoint no matter where that endpoint is. In the first generations of SPC switches, endpoints had to receive their service from the switches to which they were connected. This becomes most noticeable in wireless networks as endpoints move between switches. This means that control for one endpoint must move between service instances.

The introduction of intelligent network (IN) services began to break this restriction and provided a means for a single deployed service instance to provide a uniform experience to all endpoints. The limitation with IN is that it only applies to a small subset of all the services. Because IMS provides for endpoint signaling to go to the same service complex no matter where the endpoint is, then that endpoint user will receive a uniform service experience.

A second benefit of IP networking is the option to provide geographic redundancy. The telecommunication industry is widely recognized for developing and deploying products that meet a "five nines" level of reliability. As society becomes more and more dependent on telecommunications to provide even the most basic of services, the need is there to provide even more reliability. The use of geographically separate backup systems is one emerging trend to do this.

Although the IMS standards do not define or require geographic redundancy, the use of IP networking to connect the various components is enabling Alcatel-Lucent to offer very high redundancy with its IMS offer.

Deployment Experience and Integration Challenges

Many of the initial technology integration and deployment issues, whether foreseen or unexpected, have already arisen and been resolved. This section highlights some of these deployment experiences and integration challenges encountered during numerous trials and commercial deployments.

SIP Interoperability

Although the concept of functional partitioning with standard interfaces in a fully distributed architecture can provide benefits to operators, substantial effort is required for pair-wise and end-to-end interoperability testing to ensure seamless multimedia service collaboration. Interoperability issues detected with Session Initiation Protocol (SIP) and Session Description Protocol (SDP) [13, 21]—two protocols used for describing multimedia sessions—were found to be more prevalent in advanced SIP-based services, such as network-based presence information management and multimedia conferencing services. However, basic interoperability problems can still be found even in the simplest call scenarios. Some problems are the result of differences between Internet Engineering Task Force (IETF) standards and 3GPP/3GPP2 IMS standards. Most observed problems were due to varying levels of compliancy to numerous SIP extensions, the root causes of many incompatibilities. This issue provided field integration teams with their greatest technical challenge in diagnosing and localizing problems. End-to-end interoperability problems are also more complicated when multiple back-to-back user agents (B2BUA) [20] exist in a single call path where each can manipulate the SIP header.

It was also discovered that "SIP aware" firewalls can cause deployment problems when the threat/attack signature database is not kept current with the latest SIP extensions. For example, the "SIP aware" firewall may drop a SIP packet with a valid SIP extension header that the firewall may consider as a "malformed" SIP packet if the firewall does not recognize the extension. SIP interoperability problems cannot be completely eliminated in an IMS deployment, but can be effectively managed through accumulated in-depth protocol level knowledge and diagnostic capabilities within the field integration team.

IP Fragmentation

Session Initiation Protocol [20] recommends the use of Transmission Control Protocol (TCP) when the size of a SIP packet exceeds 1300 bytes [14]. This is to handle IP fragmentation for large User Datagram Protocol (UDP) packets [18]. TCP is a connection-oriented protocol, while UDP is a connectionless protocol. It has been documented in numerous field deployments that the size of a SIP/SDP packet can approach 1300 bytes even for a basic SIP dialog. At an extreme case, the size of a single SIP/SDP UDP packet can be more than 8 kilobytes when it carries presence information in the SDP payload (e.g., SIP NOTIFY message) [20]. The theoretical maximum size of a single UDP packet is 65 kilobytes (IP header field—2^{16}). In general, the UDP socket interface (read and write) to the operating system kernel commonly limits the size to 8 kilobytes in general computing platforms. However, it was determined that some network elements (e.g., the B2BUA server) strictly follow the RFC3261 recommendation, limiting its UDP buffer size to less than 8 kilobytes. As a result, this server was unable to re-assemble the entire UDP packet before transmitting to the next hop. Once again, diagnosis of this type of problem is not easy when encountered in the field.

Client

Instability of client software was discovered as a common issue in many of the early field trials. Resource contention was observed on mobile devices with limited hard disk space and processing power. This was especially noticeable when multimedia SIP applications ran simultaneously on a mobile device. Additionally, the complexity of some devices' user interfaces discouraged users from using enhanced multimedia services. Valuable lessons learned during these early trials were provided to the client developers, thereby contributing to a more advanced hardware platform design, improved stability, and enhanced usability of the clients in a commercial deployment.

Network Connectivity

Each operator has a unique operational infrastructure. As a result, extensive on-site re-engineering efforts were often required to deploy IMS core network connectivity into an existing operator's network. On-site switching and routing network design and implementation were error-prone and time-consuming when they involved several networking products from third party vendors. To effectively manage this issue, a reference network architecture, as a functional blueprint, was defined and delivered to the field integration teams, who then tailored it to an operator-specific model. The reference network architecture was designed to provide a basis for production level deployment, IP addressing, numbering plans, connectivity, traffic engineering, security, and failover strategy at various levels (e.g., application, platform, and geographical level). By switching to a deployment model based on a reference design, on-site design and implementation time was reduced and remote troubleshooting capabilities were improved.

Early IMS Deployment

In the IPv4 deployment environment, it is common to find clients behind a network address port translation (NAPT) device [22], which translates local network addresses and TCP/UDP ports to a publicly routable address and its port. For example, in a consumer's home network, the residential broadband gateway/modem creates a private LAN within the home and performs NAPT, thus providing some security and IP address management for the internal network. However, many application level protocols such as SIP do not work well with NAPT devices. Three approaches can be taken to resolve the resulting NAPT traversal issue for SIP/RTP traffic:

1. Use of an intelligent client capable of detecting and adapting to the NAPT device in the local network through simple traversal of UDP through network address translators (STUN) [21] or interactive connectivity establishment (ICE) [19],
2. Network-based NAPT traversal by session border controller, and
3. Use of an IPSec tunnel from endpoint to packet data gateway.

STUN and ICE allow a client to discover the presence of NAPT devices and a translated address and port. Most deployments were based on the second and third methods. The third method also provides integrity and confidentiality protection to the end user traffic.

Management Challenges

As a new technology, IMS has had its share of challenges. The good news is that implementing a standards-based, turnkey solution makes a new IMS deployment a manageable problem. The service provider's business model is a key catalyst in defining the end user services to be provided, identifying the IMS "touch-points" into the service provider's existing network, specifying the types of access networks used, and defining the nature of end user devices. Each of these aspects has a direct impact on the overall deployment architecture. Both wireline and wireless operators have some unique issues in incorporating IMS in their existing networks, including provisioning, charging, and call routing. The organizations with the responsibility for integrating the solution's network elements, application servers, devices, clients, and other equipment must address several technical and non-technical integration issues.

Alcatel-Lucent has acquired a great deal of experience designing, developing, testing, trailing, and deploying IMS architectures for multiple customers globally. Discussed later are some of the main challenges we have encountered and mechanisms used to address them.

Areas of Challenges

The main categories of challenges are technical, partner management, and integration execution. The technical challenge areas include ensuring compliance with IMS standards, understanding the end user service requirements and user scenarios, and then addressing these challenge areas into an optimal architecture, while understanding and managing circuit and packet switched network feature interactions/dependencies, providing feature parity with existing services, and addressing human factors issues. In addition, traditional functions such as performance, security, reliability, scalability, charging, and operations, administration, maintenance, and provisioning (OAM&P) are applicable across the solution. Analyzing these global areas requires an end-to-end view of the architecture while requiring detailed knowledge of the individual network elements' applicability and adherence to related requirements.

IMS network deployments, like most other networks, include multi-vendor provided network elements, handsets, and applications. A key challenge in integrating such components is to ensure their compliance with the IMS standards. These vendor interactions require a very clear set of interface requirements and component level feature definitions. Tracking vendor development activities, thorough integration testing, and thorough interoperability testing were also key aspects of the vendor management interactions.

Integration of the solution components required a very clear functional reference architecture definition mapped to specific network elements, and detailed test planning to exercise the individual and interface requirements across network elements. Detailed project management mechanisms were used effectively to ensure timely problem identification, resolution, and test plan tracking.

Risk Mitigation

The risks resulting from the challenges described were mitigated by modularizing the architecture, based on grouping related features to ensure that these functional entities were optimized to inter-work. The execution and partner management risks were mitigated by careful and thorough planning, both internally and jointly with the partners, by providing joint readouts to the customer, and by ensuring a clear channel for communication and issue escalation.

Conclusion

In this paper, we presented our experiences designing and commercially deploying a long term carrier-grade DMS solution based on an IMS architecture. The IMS-based solution allows a subscriber to roam across multiple access networks, including Wi-Fi and cellular, while using a dual mode handset. The standards-based and modular nature of our IMS platform was key to fulfilling the variety of operator requirements encountered in technology trials and commercial deployments, while meeting stringent deployment timelines. We have reviewed several architectural approaches and have summarized the different advantages and challenges in building a DMS solution. We have shown how an IMS-based solution can evolve and handle multiple services in a single IMS. A mix of Alcatel-Lucent-developed and third party best-in-class components were integrated together into a service-ready end-to-end solution. Our experience with this solution shows that the cost in terms of time and resources of integration testing, integration management, and deployment of the solution may be reduced using our solution. We expect the addition of new IMS-services will benefit from the operator investments in deploying a DMS-capable IMS solution.

Future study of this exciting topic will focus on investigating how to best merge disparate services into service bundles that are intuitive to use. We believe this will require further work in terms of both multi-modal user interfaces and network-based personalized service brokering logic. Continuing to build on the success of today's dual mode service-capable IMS platforms promises to yield benefits to operators in terms of both operational expenses and time to market for new services.

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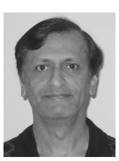

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