Future 4G Front-Ends Enabling Smooth Vertical Handovers

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Welcome to The Chip! We wish our readers all the very best in 2006!

We kick off the year with an article on handover in fourth generation (4G) wireless. While a definition for 4G is not very clear so far, there is a vision that generations beyond 3G will be able to achieve seamless, always-best-connected wireless services.This means that users of mobile devices will be able to connect to the "best" wireless infrastructure available (cellular, Wi Fi, WiMAX) anytime, anywhere where "best" could be perceived as best quality of service, best price, best security, etc. Among other things,the article addresses possible chip set solutions towards bringing this vision to reality. I hope you find it of interest.

We look forward to recieving your comments and contributions. Happy 2006!

Mohammed Ismail

This article presents an overview of the most important effects that handover considerations have on the design of multistandard mobile radio transceivers. It specifically points out the multitude of design issues and challenges that should be taken into account in the RF/analog front-end part. Many of these issues have not been widely considered yet by the relevant communities though they are instrumental in achieving an always-best-connected mobile terminal.

BACKGROUND

4G is a technology unifier that will allow several communication standards to converge in order to provide an optimum solution for a given situation. For example, as shown in Figure 1, when a mobile user connected to a cellular network enters a wireless local-area network (WLAN) hotspot, the mobile terminal may switch from using a high-mobility, low data rate standard, such as the global system for mobile communications (GSM) (licensed band), to a low mobility, high data rate standard, such as IEEE 802.16-2004, IEEE 802.16e (aka WiMAX), or IEEE 802.11b (aka Wi Fi) in order to optimize a certain set of benefits such as cost. When the user leaves the WLAN hotspot, the mobile terminal switches back to GSM or WiMAX. This scenario requires multistandard support in the mobile terminal itself, a challenge that is partly faced in this article.

This scenario will be taken to its logical conclusion, at least in the United States, when more new spectra will be made available simultaneously in the next few years than are now used by the satellite TV, PCS, and WLAN industries combined [1]. The reason for this is that the state of available radio technologies and government policies, the main issues that dictated the scarcity in available spectra in the past, are simultaneously going through a radical change.

This research focuses on handover considerations from the mobile terminal front-end designer's perspective. The issues that will be raised and researched explore the space of possible implementations of wireless front-ends by keeping in mind that, optimally, the mobile terminal, in an attempt to remain "always-best-connected," will have to continuously explore its surroundings and select the best network connection available by taking into account several factors, including the requirements of the applications that it is running. This should be done without significant interruption, optimally leading to intersystem seamless handover, at least from the user point of view. Some companies are already attempting to provide services and products dealing with these issues, such as OptiMobile AB [2] and Motorola's CN620 [3].

THE CONVERGENCE CHALLENGE

The multistandard trend will have many implications on the design of a transceiver front-end. The first is that most front-end chips on the market today either support only one standard or a few of the same family, thus having similar requirements. As a result, a device that supports a multitude of different standards will contain several front-end chips. This has severe cost, area, and power implications making this solution an impractical one, especially for consumer-oriented, handheld devices that should be small enough and have low power consumption for long-term usage.

In addition to the need to minimize the number of chips, multistandard support presents a new challenge: intersystem

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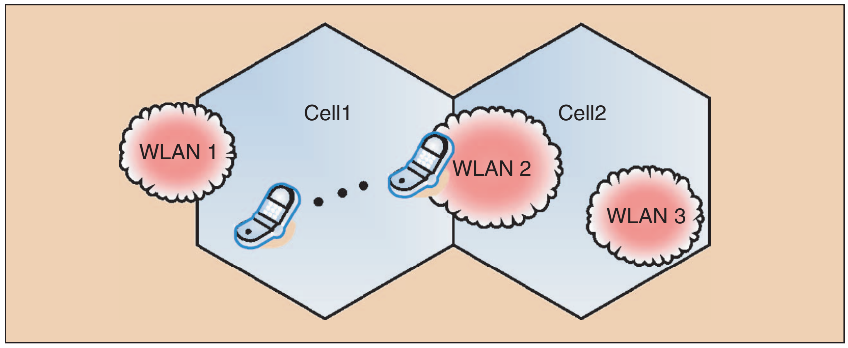
handover *while* the device is operating. Handover procedures between different systems are being studied at higher levels, but these procedures themselves may dictate a lower bound on the number of front-end multi-standard chips. This is because, while the device is communicating using one standard, it should periodically monitor its environment in order to exploit alternative wireless connections by choosing the most suitable one.

Taking the above considerations into account, will we need to implement two multistandard front-ends: one to monitor the environment and the other to keep the present applications running, or will we be able to support the required features by using a single wireless front-end that can do both jobs in a repetitively successive manner such as the Quorum Connection (QC) 2530 solution promoted by Quorum Systems, Inc. [4]? An obvious answer to the questions above does not exist, as we will see. What are the factors to look at in order to obtain an optimal implementation for a set of standards?



1. Interstandard mobility.

WIRELESS TRANSCEIVER DESIGN CHALLENGE

Over the past few decades, the success of high integration as a means for realizing fast and low-power digital systems was reflected in an ever-decreasing cost of implementation. However, RF/analog parts do not scale as digital systems do; RF front-ends, in particular, make use of many passives that make up most of the die area. For example, a voltage-controlled oscillator, an integral part of any up/down converter, contains one or more inductors, a relatively large structure. The inductance is a function of the inductor's size. This means that if we want to have a certain frequency output from the oscillator, we will have to keep (approximately) the same size of the inductor irrespective of the technology used. Therefore, the price per area of the inductor increases when it is implemented in a cutting-edge technology compared to when it is implemented in an older one. As a result, a higher percentage of the chip area will be consumed by the RF/analog part. This leads to a lower space usage efficiency, leading to lower performance/cost ratio. This will be reflected in the desire to reduce (or even eliminate) the RF/analog components as envisioned by the promoters of software-defined radios.

Multistandard devices originally are implemented by having physically different and independent radios. An example is a laptop with several connections: one through a PC card accessing the GSM network, a second to WLAN through a chipset, and a third to Bluetooth through yet another chipset. This approach worked well. However, the trend is to have this kind of multinetwork support embedded in devices no larger than a mobile phone, which pushes towards integrating these transceivers in a more efficient way.

A transceiver can, in general, be divided into two parts: the front-end RF/analog part and the back-end digital part. This division exists because these two parts were historically developed by different groups using different technologies. The digital back end has proven to be more amenable to high integration than the analog front end. As a result, we are starting to see true multistandard, single-chip, digital baseband solutions on the market, such as Sandbridge's SB3000 [5]. New architectures are being explored, such as Motorola's Reconfigurable Compute Fabric (RCF) [6] and Quicksilver's Adaptive Computing Machine [7] that can be reconfigured on the fly at run time in as little as a single clock cycle. These chips benefit from all the enhancements that come from the digital processing arena, such as parallel-processing. As a result, a single chip can be highly programmable so as to be compliant even with standards that the chip designer originally did not know of.

The analog part cannot be as generic as the digital part. More precisely, in addition to having to choose the standards that should be supported, the designer must also decide whether the chip should communicate via more than one standard at the same time, as in Figure 2. Single-chip, multistandard, analog solutions that are being used today do not have an equivalent to the parallel-processing features that the digital chips have. This is due to the fact that analog components currently must be physically switched in order to support another standard. As a result, even if true multistandard analog front-ends will be attained, the problem would be to decide on how many we should have operating in parallel. Additionally, considering the issues raised above, it is imperative to be as thrifty as possible in the number of analog front-ends, especially considering that, in general, the size of each one of them will be larger than that of a single-standard front end.

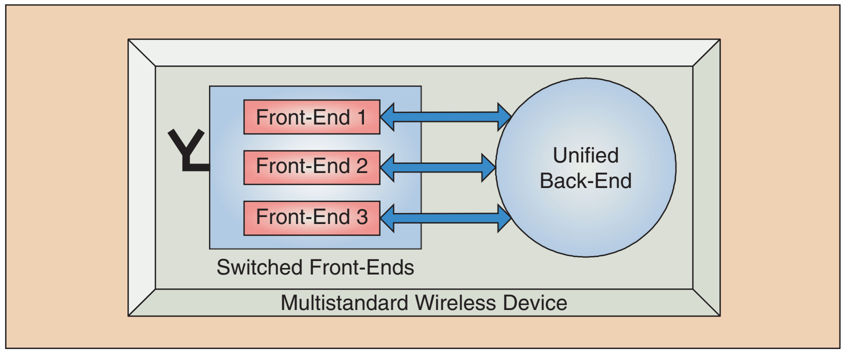
WIRELESS STANDARDS

Three types of personal communications services system integration can be identified based on their radio technologies and network technologies [8]. These types are, namely, similar radio technologies, same network technology (SRSN), different radio technologies, same network technology (DRSN), different radio technologies, and different network technologies (DRDN).

Our interest is in the compatibility between different wireless standards with respect to their radio interface. Therefore, in order to preserve generality, we are basically interested in the DRSN and the DRDN cases. More specifically, we are interested in data-link layer compatibility, since it is taken for granted that the lower physical levels will be different anyway, hence requiring physical switching in the analog front-end.

If the mobile terminal has two analog front-ends (one primary and one secondary), then the next question to be raised is whether the secondary front-end, responsible for exploring the environment (and possibly establishing connections with other networks), should support the full protocol stack. Thus, is it possible to divide the protocol stack into pieces where only the necessary pieces are implemented for every front-end?

If we take the extreme case of having a single analog front-end switching back and forth between different standards in order to explore its surrounding and/or establish a handover, then the only way it can "trick" the standards with which it is communicating is by jumping out of the communication channel in order to talk with the other standard and come back without either of them realizing the discontinuity. Thus, the device takes advantage of any "silent" time that the logical connection can provide. An example of this is the Quorum Connection (QC) 2530 that interleaves WiFi packets into unused GSM slots while still ensuring that GSM calls receive priority [4]. Both options are shown in Figure 3.



2. Current situation of device partitioning.

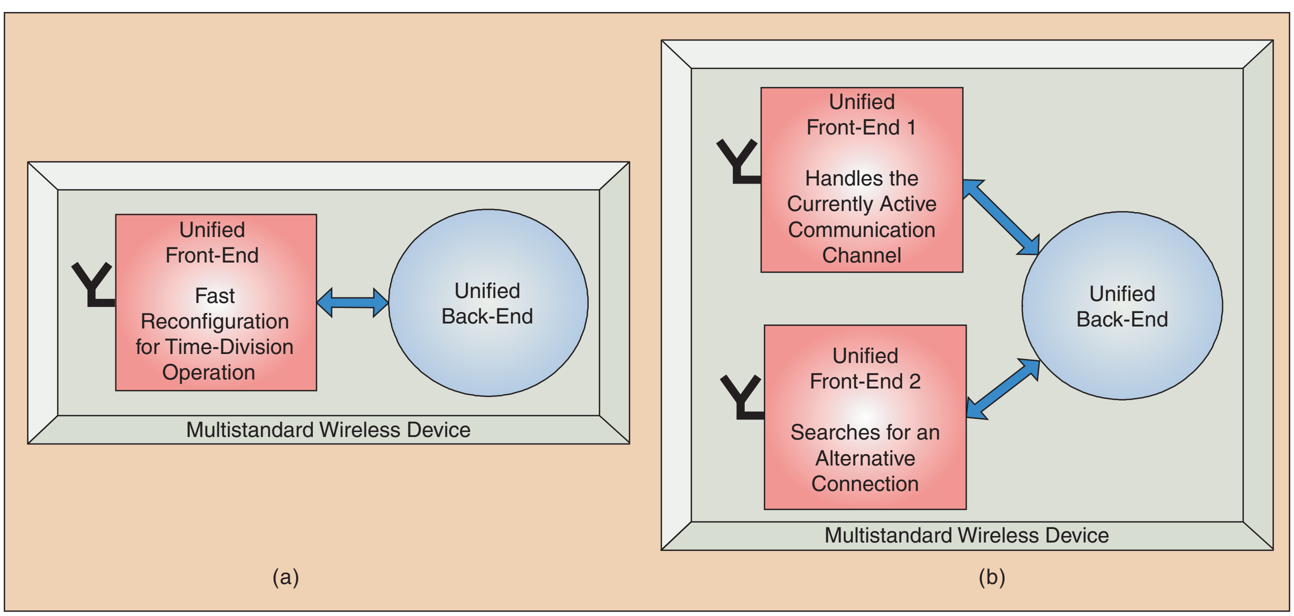
Logical-link layers are originally conceived within the realm of one standard so as to maximize the efficiency of a single network. However, little consideration is given to how much the logical-link implementation could help solve the issue raised here, i.e., when the device is involved in some inter-standard handover. Specifically we ask whether it is possible to introduce some improvements in order to harmonize this link-level layer, making it easier to switch from one standard to another. This issue has been raised a lot in the network layer and above, especially in the context of mobile IP as in the associated request for comments (RFCs) [9]. However, issues at the datalink and physical layers have not been studied deeply yet.

A summary of the chosen standards is shown in Table 1, where DECT stands for digital enhanced cordless telecommunication [10]–[12].

First, a few remarks regarding handover procedures will be made in order to have a global view of the options that are present.

HANDOVER INITIATION

Handover can be initiated either due to coverage loss in the present communication mode or if a preferred mode is detected as illustrated in Figure 4. However, standards differ in the way they measure the link in order to determine



3. Possible front-end implementations: (a) one unified front-end operating in time-division mode and (b) two unified front-ends: one for handling the current connection and one for searching for an alternative connection.

Table 1. Summary of the chosen standards.

Standard	Multiple Access	Frequency (MHz)	Channel Spacing (Hz)	Frequency Accuracy	Modulation	Data rate (bps)	Max. Power (W)
GSM	TDMA/FDMA/FDD	890–915, 935–960	200 K	±90 Hz	GMSK	270.83 k	0.8, 2, 5, 8
DECT	TDMA/TDD	1880–1900	1.728 M	±50 KHz	GFSK	1.152 M	250 m
IEEE802.11b	DSSS (CDMA)	2412–2472	5 M	±25 ppm	DBPSK	1 M	1
					DQPSK	2 M	
					CCK	5.5 M	
						11 M	

the quality of the channel. In general, there are two metrics that are used to determine the quality of a channel in order to do a handover [8]:

- ✦ *Received signal strength indication (RSSI)*—As a measure of received signal strength, the RSSI metric often has a large useful dynamic range, typically between 80 and 100 dB.
- ✦ *Quality indicator (QI)*—Estimate of the "eye opening" of the radio signal, which is related to the signal to interference and noise (S/I) ratio, including the effects of dispersion. QI has a narrow range (from about 5 to perhaps 25 dB).

Ideally, the handover decision should be based on distance-dependent fading and, to some extent, on shadow fading, but not on multipath fading which can be addressed by other methods.

However, the problem that arises in multistandard situations is that handover may be vertical, i.e., from one standard to another. This will affect the initiation of the handover. Handover may be mobile controlled (such as in DECT), network controlled, or mobile assisted (such as in GSM). In our scenario, it is preferable that the handover be mobile controlled, since of all the components in the network, the mobile terminal has the best perspective of what alternative links it can handover to. On the other hand, the network should also be informed so traffic is routed to the new connection. The handover itself can take between 100 and 500 ms for DECT and up to 1 s for GSM.

A good starting point for the interstandard handover study is the interworking between GSM and DECT. A standard has already been published regarding this (see the next section). Afterwards, we will try to extrapolate from this standard in order to include a low tier (narrow-range) standard other than DECT, such as IEEE 802.11b.

INTERWORKING BETWEEN GSM AND DECT

The European Telecommunications Standards Institute (ETSI) specifies additional requirements to the existing GSM and DECT standards needed for DECT/GSM mobile terminals that can be manually switched between DECT and GSM mode and/or can perform background scanning and switch automatically and/or can have both modes activated at the same time [13]. This standard provides a good starting point to study mobile terminal interoperability between GSM and other standards.

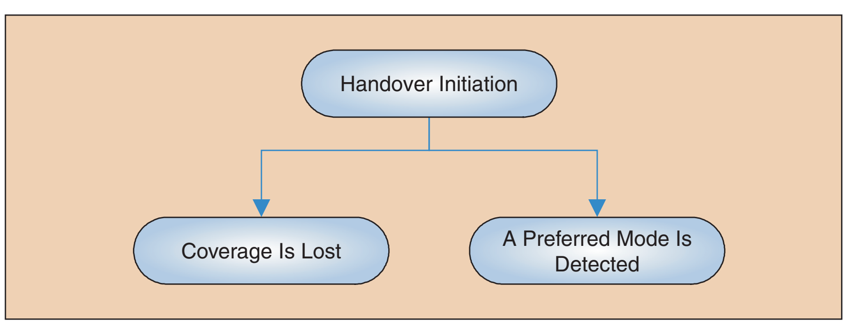
Terminal Configurations

A mobile terminal for DECT and GSM is considered to be a terminal with one GSM part and one DECT part that is controlled by a common interworking unit that also controls a common interface.

Some parts in the terminal, such as microphone and loudspeaker, could be reused by both the GSM and DECT parts or could be duplicated. Integration of the RF parts is also foreseen. Several possible hardware configurations can be envisioned for such a mobile terminal. For example, the terminal could contain two entirely separate transceivers, simply sharing the keyboard, display, microphone, earpiece, etc. Completely independent operation may then be possible, but there will be difficult technical issues of receiver blocking to overcome. It is also possible for parts of the transceivers to be common, reducing the cost of the terminal, but also limiting the possibilities of simultaneous operation. The exact functionality of the interworking function will depend on the terminal configuration.

The different possible radio configurations may also have an impact on the networks. They will also affect the performance specifications, which the terminals can meet. However, it is undesirable to have different regulatory requirements dependent on the implementation of a mobile terminal, so this should be avoided.

Five general terminal configurations denoted as Types 1–5 have been identified [14]. The essential differences between the terminal types are summarized in Table 2. The Type 3 terminal is subdivided into *a* and *b* categories depending on whether simultaneous reception is supported.



4. Conditions under which handover is initiated.

Table 2. Summary of terminal types.

Terminal Type	Number of Location Registers	Air Interface Selection	Simultaneous Receive	Simultaneous Dual-mode Receive Transmit	Simultaneous Transmit
1	1	manual	no	no	no
2	1	automatic	yes or no	no	no
3*a*	up to 2	automatic	yes	no	no
3*b*	up to 2	automatic	no	no	no
4	up to 2	automatic	yes	yes	no
5	up to 2	automatic	yes	yes	yes

Of these mobile terminal types, Type 1 is the only truly basic type, Types 2 and 3 are identified as interesting for early implementations, and Types 4 and 5 are considered as advanced and are for later implementations.

General Switching Behavior

The mobile terminal is in GSM or DECT mode, or it could have both modes activated at the same time. In each mode, in general, the mobile terminal shall operate as the corresponding single mode terminal and shall fully comply with the relevant standards for that single mode terminal. When one mode is being activated or deactivated, the mobile terminal shall operate like a single-mode terminal that is switching on or off. Location registration within each mode shall be performed according to the relevant standards for single-mode terminals and the behavior when switching modes is the same as when a single-mode terminal is switched off and the second terminal is switched-on.

The possible ways of a mobile terminal dealing with several air interfaces are stated below and in Figure 5:

- ✦ Manually switched operation (the mobile terminal behaves as a GSM mobile terminal or as a DECT mobile terminal)
  - GSM-only mode
  - DECT-only mode.
- ✦ Automatically switched operation (the mobile terminal behaves as a GSM mobile terminal or as a DECT mobile terminal and can switch automatically between GSM and DECT modes), where the old mode is switched off *before* the new mode is switched on.
- ✦ Parallel operation (both DECT and GSM modes are activated and the mobile terminal is registered in both GSM and DECT networks)
  - active communication is only possible in one mode at the same time, or
  - active communication is possible in both modes at the same time.

Our interest is in the automatically switched operation, since this is the case where the scenario given at the beginning can be applied. Parallel operation is also possible, but at the expense of having as many front-ends as the standards supported.

Automatically Switched Operation

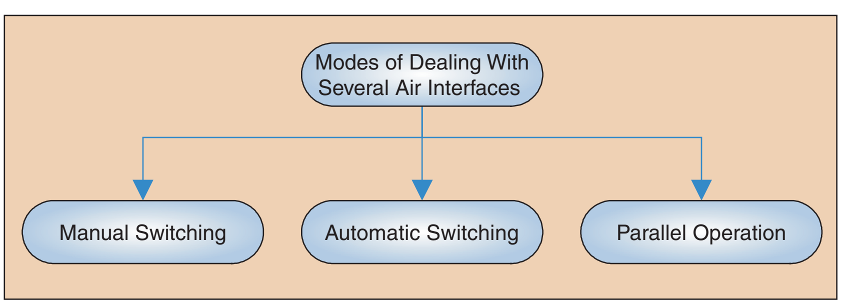
Automatic switching includes a background scanning procedure whose function is to check on the possibility to get normal service under stable coverage conditions in the mode other than the one the device is currently in. Background scanning is done without leaving the currently active mode. It is a procedure consisting of three steps:

1) searching for coverage in the nonactive mode
2) identifying the presence of a network found in step 1 to which the mobile terminal has access rights as far as the information broadcast allows this to be determined (As the requirements of the mode the terminal is currently active in need to continue to be kept, the terminal may receive some information broadcast during the background scan but shall not set up an active communication in the other mode. However, there are exceptional cases where it may not be possible for the mobile terminal to identify if it has valid access rights, e.g., active communication may be needed to confirm that full GSM service is available.)
3) checking the stability of coverage.

If the terminal does have sufficient access rights according to Step 2 to one of the networks found in Step 1, it should check the stability of the coverage of this network. One criterion for stability could be the field strength measured by the terminal during a certain time interval.

In order to save battery power, the whole scanning procedure may be a periodic process.

Switching may be performed automatically, as a result of a background scan, or manually, following user notification of the result of a background scan. Switching of modes may be the result of a background scan if the new network is to be found stable according to Step 3.



5. Possible ways of dealing with several air interfaces.

The automatic switch between DECT and GSM modes in the mobile terminal can be initiated as follows:

- ✦ based on loss of coverage—switching due to loss of coverage need not be immediate and may wait for a manual acceptance from the user before being executed since it may happen that the user does not want to switch to a more expensive connection for example
- ✦ based on the result of a background scan—identifying coverage in the mode other than the one it is currently in.

In other cases, the mobile terminal automatically selects GSM or DECT mode with respect to the preferred mode defined by the user.

Thus, three alternatives are found in the automatic mode-selection procedure: one alternative for loss of coverage, one for background scanning where no preferred networks are found, and one for background scanning, which results in a change of mode.

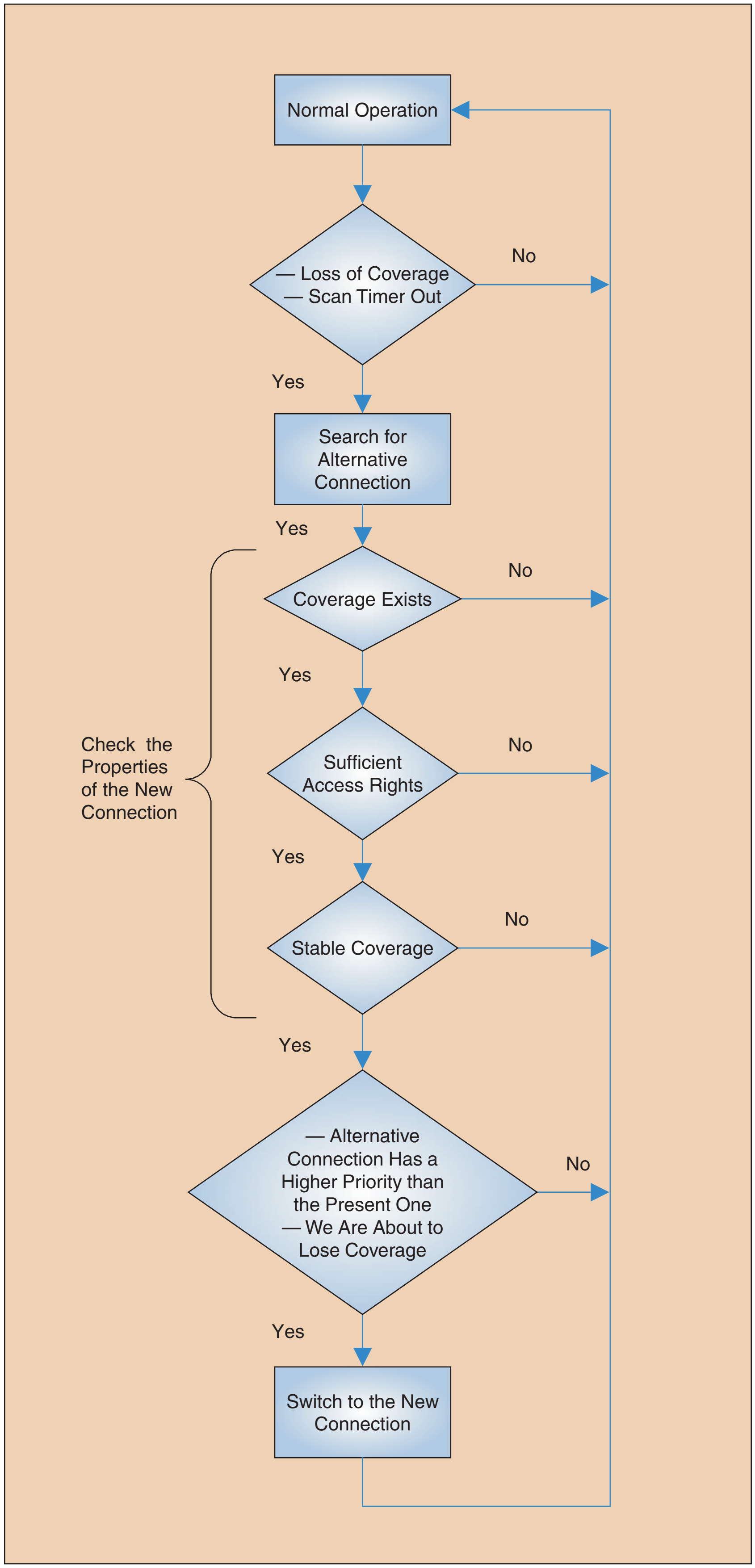
To avoid excessive signaling load in the networks due to frequent switching between the two modes as a result of background scanning, a timer is implemented to provide hysteresis in the mobile terminal. This requirement applies irrespective of why the mobile terminal switched from one mode to another. It is advantageous for the mobile terminal to wait for stable coverage before switching modes in order not to be restricted from further switching by the timer too often. There is no limit on the frequency with which a mobile terminal may switch mode due to loss of coverage; however, frequent switching may lead to excessive battery drain. Figure 6 summarizes the procedure that the mobile terminal follows.

Identified Problems

In the extreme case of having one front-end, a Type 2 (or 3*b*) terminal will be of particular interest. Therefore, here we will focus on this case.

IDLE MODE ISSUES

Mobile terminals of Type 2 use a single time multiplexed receiver and, hence, cannot simultaneously receive in both DECT and GSM modes.



6. Procedure that the mobile terminal follows when dealing with more than one air interface.

There are a number of processes that a mobile terminal needs to carry out in the idle mode on an active air interface, in particular:

- ✦ cell reselection processing
- ✦ decoding of broadcast information
- ✦ listening to paging messages.

In the inactive interface, the Type 2 mobile terminal has to check for service availability. This requires measurements of received radio signal strength and access rights evaluation.

For Type 2 terminals, two potential consequences of the need for background scanning using the inactive mode have been identified:

a) There is a potential loss of idle locked mode performance over the active air interface compared with a single mode phone, which may result in:
   - some loss of paging messages
   - reduced update rate of broadcast information
   - delayed cell reselection.

b) There is also an increase in the detection time of service availability from the inactive air interface compared with a single mode phone.

It is desirable that idle performance of the active air interface not be degraded. However this may not be practical. If so, the maximum acceptable level of degradation of each of the parameters discussed in a) needs to be defined and a balance struck between these effects and the increase of service detection time mentioned in b). This is an area where new requirements may need to be set.

MISSED PAGES

Paging being missed by the mobile terminal will force the networks to take actions as if the terminal is not reachable—even if it is generally present. Paging messages may be missed by a Type 2 mobile terminal when it is scanning the other air interface. This problem could be reduced by intelligent scanning, i.e., not scanning when expecting a page on the other interface.

The consequence of scanning the other air interface is that, for Type 2 mobile terminals, pageability is degraded. This degradation ought to be limited by setting an upper limit for lost pages. This upper limit has to take into account both operators' needs as well as manufacturers' possibilities.

Requirements on Parallel Operation

In addition to having to comply with both standards, the following requirements on mobile terminals with parallel operation implemented, i.e., mobile terminals operating with both modes (DECT and GSM) activated at the same time, should be fulfilled [15]. The behavior that these type of terminals can provide is taken as the ideal case and should be targeted if another low tier architecture is used.

A mobile terminal that simultaneously at least receives in both DECT and GSM modes and is simultaneously registered to both DECT and GSM at the same time (thus a Type 3 or greater mobile terminal) is a parallel mode mobile terminal (i.e., a mobile terminal in parallel operation). A mobile terminal in parallel operation shall comply with all of the idle mode requirements for both DECT and GSM. Additionally, when in active communication in one mode (DECT or GSM), the mobile terminal:

- ✦ shall not leave parallel operation
- ✦ shall meet the idle mode requirements of the other mode.

The active communication may be an outgoing call, a terminal-initiated procedure, or a response to a page from the network, which in turn may be an incoming call or a network-initiated procedure.

If the mobile terminal is incapable of responding to any paging messages in the other mode (GSM or DECT) while in active communication in one mode, then it shall behave as though out of coverage in the other mode.

If the mobile terminal is capable of responding to paging messages in the other mode (GSM or DECT) while in active communication in one mode, then it shall not do so unless it is capable of handling parallel active communications.

PROCEDURE WHILE IN ACTIVE COMMUNICATION IN DECT MODE

When the mobile terminal is paged in the DECT mode, or when the mobile terminal initiates an active communication in DECT mode, it shall not perform the detach procedure in the GSM mode; it shall respond to the DECT page within the time required by the DECT standards. This is dictated by the {LCE_REQUEST_PAGE} message resubmission timer <LCE.03>, which is 3 s [16].

If the GSM network requires periodic location updates in GSM mode, the T3212 timer in the GSM part of the mobile terminal shall be kept running during DECT active communication. If this timer times out before the DECT communication is finished, then as soon as the DECT communication is finished, a location update shall be performed in the GSM mode.

When in active communication in the DECT mode, if the mobile terminal is paged in GSM mode, and the mobile terminal has detected this page and is incapable of responding to it, then as soon as the DECT active communication has finished, the mobile terminal shall perform a location update in the GSM mode.

If this paging was due to an incoming short messaging service (SMS) message, then it is likely that the SMS would be sent again following the location update. If the paging was due to an incoming call, and the user had the call divert to a voice mailbox activated on no reply, then it is likely that an SMS message would have been sent to the user to notify him of a message in his mailbox (in which case there would have been two sets of pages), and he would receive this SMS following the location update.

PROCEDURE WHILE IN ACTIVE COMMUNICATION IN GSM MODE

When the mobile terminal is paged in the GSM mode, or when the mobile terminal initiates an active communication in GSM mode, and the mobile terminal implements the cordless terminal mobility access profile (CAP) on the DECT mode, it shall not perform the detach procedure in the DECT mode. It shall respond to the GSM page within the time required by the GSM standard, which is determined by the timer T3313 (network dependent) [17].

If the DECT CAP network requires periodic location registration in the DECT mode, when the mobile terminal implements the DECT CAP profile, the corresponding timer in the DECT part of the mobile terminal shall be kept running during the GSM active communication. If this timer times out before the GSM communication is finished, then as soon as the GSM communication is finished, a location registration shall be performed in the DECT mode.

Figure 7 summarizes the actions that the mobile terminal should perform while operating in GSM and DECT modes.

GSM/WLAN HANDOVER

In this section, we will extrapolate from the previous section in order to include GSM and IEEE 802.11b. These two wireless standards were chosen based on the fact that they are very different and can be treated as complementary (as illustrated in the scenario described in the introduction). In general, the main advantage of the GSM network is that it covers a very wide area while being accessible to the public. The main advantage of a WLAN network is that it is cheap and fast, although it may not be always open to a specific user. However, the GSM network is rather expensive to access (compared to WLAN) and quite slow, while WLAN is **not** present everywhere.

Although these networks provide a good case from an application point of view, their underlying technologies are quite different, thus providing a relatively difficult scenario in terms of integration.

Moreover, handover in WLAN does not yet have a published standard. GSM handover between base transceiver stations (BSTs) is well documented [18], but handover between access points for IEEE 802.11b is under development. On 14 July 2003, the IEEE released the trial-use recommended practice for multivendor access point interoperability via an inter-access point protocol across distribution systems supporting IEEE 802.11 operation (IEEE 802.11F [19]).

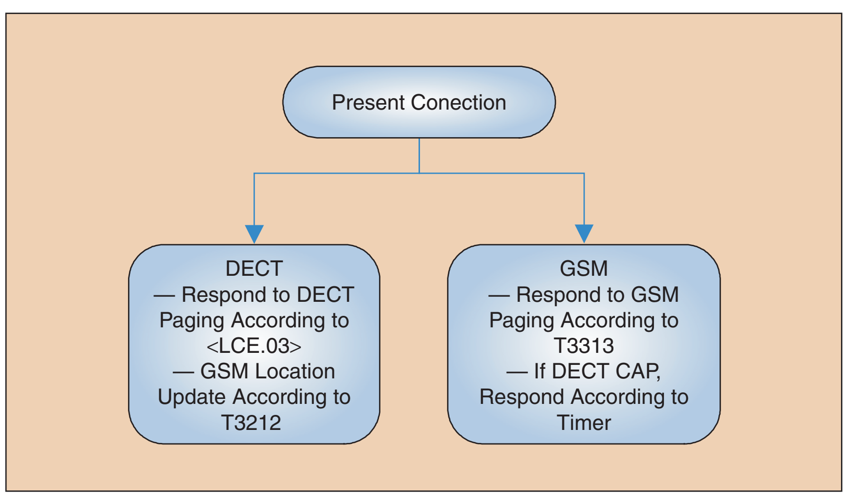
Previous Studies

Some studies are being conducted on forwarding schemes in order to reduce packet loss during inter-basic service set (BSS) handover in IEEE 802.11b [20]. Having observed that there are limitations in the network-layer forwarding scheme, the authors of [20] focused on the link layer. Their solution included having buffering and image queues in the device driver in order to recover most of the packets that would have been otherwise lost, including those held in the network interface card. However, their experimental results showed that their scheme translated directly to less (or no) packet loss and much better perceived application-level quality for the user datagram protocol (UDP) than for the transmission control protocol (TCP) when the TCP retransmission timeout is smaller than the handover delay.

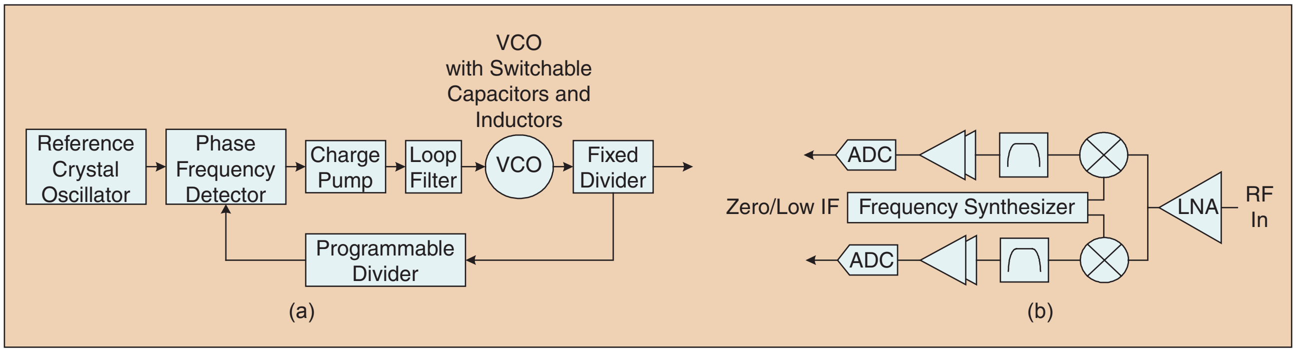
Other studies are being conducted that include handovers between general packet radio services (GPRSs) and WLAN [21]. In this particular study, the authors aimed to have quasiseamless interdomain handover between distant WLAN domains by means of temporary GPRS access to the Internet. When the user brings the mobile terminal outside the radio boundaries of its home WLAN domain, the device automatically detects the loss of the WLAN signal and diverts all IP connections to the GPRS interface. The connections are seamlessly switched back to the WLAN interface as soon as a WLAN access point signal is available. This is made possible by implementing a middleware called "WiFi Bridge," which is based on improvements of the open-source Cellular IP (CIP). These improvements include enhancements of the protocol stacks implemented at the gateway and the mobile terminal. In addition to the mobility tasks derived from the CIP gateway, the implemented gateway is responsible for registration management, IP tunnel management, packet classification, and packet forwarding. More details can be found in [21]. The mobile terminal used is a PDA device with an IEEE 802.11b PC-card installed on it. The PDA is also attached to a mobile phone through a Bluetooth connection. In this manner, it can also access the GPRS network.

When the mobile terminal moves outside of its home WLAN domain radio range, it sets as a default route for outgoing packets to the GPRS network, actually performing a hard handover from WLAN to GPRS.

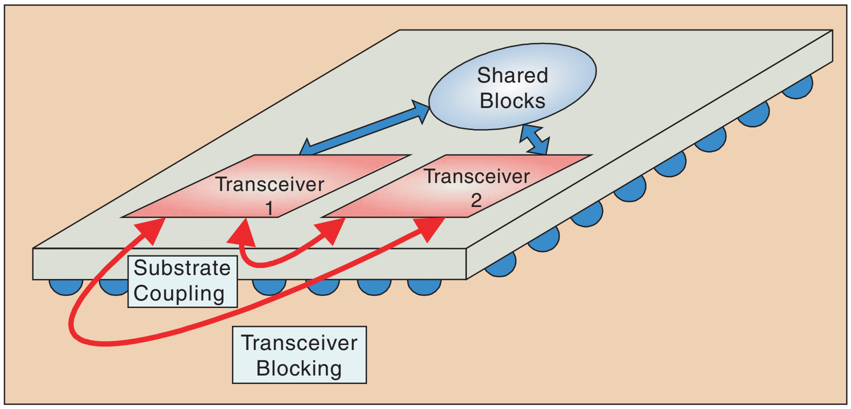
When the mobile terminal moves back inside its home WLAN domain, it receives a beacon advertisement message, coming from the nearest in-range



7. Satisfying the requirements of GSM and DECT while in active communication in either one of them.



8. Examples of a frequency synthesizer (a) and a receiver chain (b) suitable for integrated multistandard front-ends.



9. Additional issues to resolve when both transceivers are present on the same chip.

base station of the WLAN domain. This message provokes the awakening of the mobility management thread inside the mobile terminal that resumes its execution and consequently sets that advertising base station's IP address as the default route for its uplink packets. After this, the mobile terminal still keeps on receiving packets from the GPRS tunnel. In fact, it still has to wait for the expiration of the last resumed paging-update timer before it can expressly signal its presence to the WLAN domain, sending a paging-update message. As soon as the home gateway receives the paging-update message it sets-up a default route toward the mobile terminal back to the WLAN domain route. Due to the fact that a soft handover is actually performed, the mobile terminal receives IP packets from both access interfaces, WLAN and GPRS, for the brief period of time intervening between the awakening of the mobility management thread in the mobile terminal and the actual update in the gateway of the routing path to the mobile terminal.

This study has showed that, even by having two front-ends working in parallel, packet losses are experienced by the mobile terminal during the WLAN to GPRS handover. This is due to the bandwidth mismatch between the two environments and the hard type of handover performed. Additionally, when going from GPRS to WLAN, the mobile terminal keeps on receiving packets from both interfaces at the same time for a brief period. Thus, simultaneous reception should be supported. This requires a mobile terminal with two transceivers.

RF Front-End

Combining the results above raises very interesting issues for the front-end designer. These issues are not dealt with yet in relevant circles, although they will be of great importance in the years to come.

Until now, a lot of work has been done to support all the different flavors of WLAN in a single integrated solution such as in [22]. Additionally, we have identified possible front-end architectures and frequency planning and generation schemes that are amenable to support E-GSM, DCS1800, WCDMA, and WLANb/g. The scheme consists of using a reference frequency synthesizer running at a multiple of the RF frequency then using low-noise dividers to scale the frequency down, as in Figure 8(a). The frequency synthesizer makes use of a voltage-controlled oscillator (VCO) with switching inductors and capacitors to broaden its output range. All this can be incorporated in a zero-/low-IF transceiver architecture. An example of a receive chain is shown in Figure 8(b).

However, if we want to have real inter-standard operability without having to miss any broadcast information or paging messages in the idle mode or to be able to do efficient background scanning of alternative links, then at least two front-ends should be implemented. This is made clear in the GSM/DECT interworking standard, where the intention was to avoid changing the standards themselves while having a mobile terminal that conforms to both standards. This is also made clear when they define parallel processing for terminals with two transceivers.

The fact that two front-ends co-exist on the same chip raises a lot of frequency planning and coexistence issues not only within each one of them, but also between them. For example, spurious tones from a mixer in one of them may leak into the signal path of the other, thus corrupting the information. Another example is when the signal leaks from the transmission part of one front-end to the reception part of the other (transceiver blocking), as in Figure 9. These issues reveal a lot of interesting and new directions for research and development. Additionally, inventive solutions are very likely to be patented, since such issues have not been of great interest in the mass consumer market before. This is because, in addition to the fact that many consumer-oriented wireless standards are now present on the market and are widely used unlike earlier times when this was true for very few standards, it is getting clearer that not one of them is able to provide an optimal solution under all conditions from an economical as well as technical point of view. However, by being able to use them selectively through multistandard support, the user can have a desirable connection anytime, anywhere—hopefully at a more suitable price.

Another issue to raise is whether the secondary front-end, responsible to explore the environment and establish connections with other networks, should support the full protocol. Thus, is it possible to divide the protocol stack into pieces where only the necessary pieces are implemented for every front-end? This may not affect the physical layer but may affect the upper layers.

An interesting field of research is from a standard development point of view. More precisely, what features of a standard can ease its integration with other standards from a transceiver front-end design perspective? Would it be desirable to do some sort of standard pooling that involves allocating some common channels where a transceiver can directly inquire about all the links that are available, something similar to an information desk in a building?

CONCLUSION

This study has focused on a new field of research that combines the support of several standards in a mobile terminal that can actively choose its preferred connection. A lot of future research is needed in order to pinpoint the specific implementation problems and to quantify them. This can be based on the previous work done for GSM/DECT but in the light of the new technologies at hand. The issues that were raised are very interesting, and their solutions are amenable to be developed themselves into new standards in the future.

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