1. **Introduction:**

In the telephone networks, the circuit between the subscriber's equipment (e.g. telephone set) and the local exchange in the central office is called the subscriber loop' or & local loop'. Traditionally, the copper wire has been used as the medium for local loop to provide voice and voice-band data services. Since 1980s, the demand for communications services has increased explosively. There has been a great need for the basic telephone service, i.e. the plain old telephone service (POTS) in developing countries. On the other hand, in the industrialized countries, the demand for high-speed data and multimedia services at home and/or office has increased continuously. These requirements have been a motivation for innovation in local loop. There are two remarkable challenges in local loop technologies.

a. One is mainly from the expansion of landscape in service types. Owing to drastic growth of Internet, to access Internet at home (or office) became an usual lifestyle today. Moreover, to enjoy multimedia services at home will not be strange in near the future. These services require broadband local loop systems. To deal with this situation in short term, the digital subscriber line (DSL) technologies, including high-bit-rate DSL (HDSL), asymmetrical DSL (ADSL), and very high-bit-rate DSL (VDSL), have been studied and developed.

b. Another technical advance, on which we will focus in this report, is the wireless local loop (WLL) adopting radio as the transmission medium. WLL is often called the radio local loop (RLL) or the "fixed wireless access” (FWA). And WLL services are also referred to as the "fixed cellular services”. WLL has many advantages from the viewpoints of the service providers and subscribers:

   i. The WLL approach significantly speeds the installation process since it can eliminate the wires, poles, and ducts essential to wired
networks. Thus, WLL systems can be rapidly developed, easily extended, and are distance insensitive. Since WLL is a quick start for startup systems, wireless access is one of the viable means to meet the high demand for POTS in many developing countries.

ii. The operations and maintenance are easy and the average maintenance time per subscriber per year is short (40 min compared to 2.2 h for wireline).

iii. Using advanced digital radio technologies, WLL can provide a variety of data services and multimedia services as well as voice.

iv. Among radio systems, WLL enjoys the merits of fixed system: using high-gain directional antennas, the interference decreases. This reduces the frequency reuse distance, increases the possible number of sectors in a sectored cell, and increases, in turn, the system capacity.

Since WLL is a kind of radio system, it is natural that the WLL technologies have been affected by wireless mobile communication technologies. In fact, as will be shown later, most of the WLL systems are developed according to the standards (or their variants) for mobile systems. Basically, almost all the wireless systems or multiple access techniques can be used for WLL. However, it is also true that there exist some technologies or systems that have comparative advantages in a certain WLL environment. The reference frame for comparison between systems is given by the service requirements in a specific service area. In this report, we investigate WLL services. The insight into WLL services gives:

a. as mentioned above, the reference for comparison between several systems or technologies available for WLL, and

b. some prospects of future WLL services that can be a motivation for further study and development of systems.

2. WLL SYSTEM ARCHITECTURE

Since WLL systems are fixed, the requirement for interoperability of a subscriber unit with different base stations is less stringent than that for mobile services. As a result, there exist a variety of standards and
commercial systems. Each standard (or commercial system) has its own air interface specification, system architecture, network elements, and terminology. Moreover, although the network elements in different systems have the same terminology, the functions of the elements may differ according to systems. In this section, we present a conceptual (and typical) architecture of WLL systems (see Figure 1).

![Figure 1. Typical architecture of WLL.](image)

- The fixed subscriber unit (FSU) is an interface between subscriber's wired devices and WLL network. The wired devices can be computers or facsimiles as well as telephones. Several systems use other acronyms for FSU such as the wireless access fixed unit (WAFU), the radio subscriber unit (RSU), or the fixed wireless network interface unit (FWNIU). FSU performs channel coding/decoding, modulation/demodulation, and transmission/reception of signal via radio, according to the air interface specification. If necessary, FSU also performs the source coding/decoding.

  When a dummy telephone set is used, FSU may perform dial-tone generation function for users so as not to be aware of WLL system. FSU also supports the computerized devices to be connected to the network by using voice-band modems or dedicated data channels.

There are a variety of FSU implementations. In some types of commercial products, an FSU is integrated with handset. The basic functions of this integrated FSU are very similar to those of the handset for mobile communications, except that it does not have a rich set of functions for mobility management. Another example of FSU implementation is a high-capacity, centralized FSU serving more than
one subscriber. Typical application of this type of FSU can be found in business buildings, apartment blocks, and the service area where some premises are located near by (see Figure 2).

![Figure 2. Fixed subscriber unit serving multiple subscribers.](image)

- A BSC controls one or more BTSs and provides an interface to the local exchange (switch) in the central office. An important role of BSC is to transcode between the source codes used in wired network and that at the air interface. From the above roles, a BSC is often called the radio port control unit (RPCU) or the transcoding and network interface unit (TNU). WLL systems do not need to offer mobile services basically, even if some systems provide limited mobile services. Thus, for example, there is no home and visitor location register (HLR/VLR) in a WLL system and its overall architecture may be simpler than that of the mobile systems.

As one can easily guess from Figure 1, the WLL services depend not only on the functionality of FSU, BTS, BSC, and air interface specification but also on the service features provided by the switch in the central office. For example, when WLL is used as a telephony system, there are the basic telephony services and supplementary services. If the air interface provides a transparent channel to the switch, these service features depend totally on
the switch functions. So, we hereafter focus on the air interface specifications related to WLL services rather than the service features by the switches.

3. **WLL SERVICE REQUIREMENTS**

The communication service requirements depend heavily on the socio economical situations of the service areas. In general, the WLL services required in developing countries and/or regions can differ from those in developed ones.

3.1 **Developing countries/ regions**

For these areas, the emphasis points of WLL service requirements can be summarized as follows:

i. In terms of service coverage, a wide area should be covered within a relatively short period.

ii. Especially, for the regions with dense population, a high-capacity system is indispensable. Here, capacity means the available number of voice channels for given bandwidth.

iii. On the other hand, there may exist wide areas with sparse population. For these service areas, if a small population with low traffic load resides near by, a centralized FSU serving more than one subscriber can be a solution (see Figure 2).

iv. The service fee per subscriber must be low so as to offer the universal service. For this, a high-capacity system is again needed and the cost of system implementation and operation should be low.

v. The system should be implemented rapidly so that the services might be launched quickly. In choosing systems, the possibility of the rack of social overhead capitals (e.g. loads or electronic power) in some areas also should be considered.

As a tradeoff to fulfill the requirements of high capacity with low service fee, a medium-quality and relatively low data-rate of channel (typically, up to 16 kbps) may be unavoidable. Using this channel, only voice and/or voice-band low-speed data communications are possible. However, the service requirements to the advanced services (e.g. high-speed data and broadband communications) will arise after (or with) the penetration of
POTS. Therefore, at the initial choice and installation of WLL system, the service provider should take into account the future evolution of system to provide advanced services.

3.2 Developed countries/regions
In the developed countries and/or regions, the service requirements contain not only POTS but also other advanced services. It is usual that more than one local switching service providers and cellular mobile service providers coexist in these service areas. We examine the WLL service requirements from the standpoint of each service provider.

WLL provides a means to establish local loop systems, without laying cables under the ground crowded with streets and buildings. Thus, WLL is regarded as one of the most attractive approaches to the second local switching service providers. Unfortunately from the second providers' perspective, there are one or more existing providers (i.e. the first providers), who have already installed and operated wireline networks. To meet the increasing and expanding users' service requirements for high-speed data and multimedia services as well as voice, the first providers try to evolve their networks continually (for example, using DSL technologies). The second providers, entering the market in this situation, should offer the services containing competitive ones in terms of service quality, data rate of channel, and supplementary services, etc. That is, the WLL channel of the second provider should be superior to or, at least, comparable with the first operators' one in quality and data rate. Therefore, WLL should provide toll quality voice and at least medium-speed data corresponding to the integrated services digital network (ISDN) basic rate interface (BRI, 2B#D at 144 kbps). In addition, to give subscribers a motivation to migrate to the new provider, the service fee of the second provider needs to be lower than that of the first operators. Even to the first local switching service providers having wireline networks, WLL can be a useful alternative for their network expansion. Most countries impose the universal service obligation (USO) upon the first operators. In this case, WLL can be considered as a supplementary means to wireline networks, for covering areas with sparse population, e.g. islands. The first service requirement for this application of WLL is the compatibility with and the transparency to the existing wireline network.

On the other hand, the cellular mobile service providers can offer easily WLL services by using their existing infrastructure for mobile services. In this case, fixed WLL service may have competitiveness by combining with
the mobile services. For example, these two services can be offered as a bundled service. In addition, the so-called one-phone service can be offered with an appropriate billing strategy. That is, with a single subscriber unit, a subscriber enjoys the fixed WLL services at home and the mobile services on the street.

Table I gives a comparison between the WLL services using a dedicated network and the mobile/WLL bundled services. Note that the table also contains the pure cellular mobile services for the purpose of comparison.

<table>
<thead>
<tr>
<th></th>
<th>WLL only service</th>
<th>Cellular mobile service</th>
<th>Mobile/WLL bundled service</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Network elements</strong></td>
<td>Local exchange/ BSC/BTS/FSU</td>
<td>MSC/BSC/BTS</td>
<td>MSC/BSC/BTS</td>
</tr>
<tr>
<td><strong>Sub. unit</strong></td>
<td>FSU with wireline feeling (dial tone)</td>
<td>Mobile handset</td>
<td>Mobile handset, FSU</td>
</tr>
<tr>
<td><strong>Services</strong></td>
<td>No (or low) mobility, Medium-to-high speed data, supplementary</td>
<td>High mobility, Low-to-medium-speed data.</td>
<td>Low/high mobility, Medium-to-high speed data, supplementary services.</td>
</tr>
</tbody>
</table>

4. **Alternative Wireless Local Loop Solutions**

In a most general sense, wireless local loop (WLL) can be segmented into four major categories:
- Technologies based on cellular mobile radio standards
- Technologies based on cordless mobile radio standards
- Proprietary WLL technologies
- Microwave technologies

4.1 **Cordless Technologies**

Cordless technologies were designed to replace wired phones to provide limited mobility. Due to the low ranges originally required between the portable subscriber station and the cordless home base station (typically around 200m), low power designs were used. Further, to keep the base
station inexpensive, the phone designs were kept simple, avoiding complicated speech coders, channel equalizers, etc. Frequency planning was also not possible as users owned the base station as well as the mobile, so the phones needed to seek a low-interference channel whenever they were used. Today, WLL technologies that developed from these cordless technologies retain much of the original characteristics. Specifically, cordless technologies are low range and high capacity. The main cordless technologies include DECT, PHS, and CT-2.

4.1.1 DECT
Digital European Cordless Telephone (1.88 - 1.9 GHz) was standardized by the European Telecommunications Standards Institute (ETSI) in the early 1990's, initially for use as wireless office PABX (private access branch exchange). DECT transmits using TDMA techniques. Each radio channel is 1.728 MHz wide into which a DECT carrier with data rate of 1.152 Mbps is inserted. Radio channels are spaced at 2 MHz apart. Each 1.152 Mbps is divided into 24 time slots. Nominally, 12 time slots the downlink (base station to subscriber) and 12 for the uplink. This channel allocation can be varied dynamically. Because there is transmission in both directions on the same frequency, DECT is time division duplex (TDD), meaning that the transmission time is divided between the different directions in a half-duplex mode. The TDD technique leads to simpler radio frequency (RF) design. Within each of the 24 slots, a 32 kilobits per second (Kbps) bearer capability is provided. Thus, the slots can be concatenated to provide up to 552 Kbps per user (18 slots) as long as most other users are kept from accessing the base station at the same time. Like most other cordless based technologies, DECT has too short a range and may require too many base stations if the subscriber base is sparsely populated.

4.1.2 CT-2
Cordless Telephony System 2 (CT-2) operates in the 864.1 to 868.1 MHz band, using FDMA with channel bandwidths of 100 KHz. Within the FDMA channel, TDD and DCA are used. Each channel can carry 32 Kbps in both directions, providing ADPCM voice coding. CT-2 cannot concatenate time slots and thus lacks the bandwidth flexibility of DECT.
In general therefore, cordless technologies are particularly well suited to areas of very high density - they have been deployed with great success in high density cities in Eastern Europe. However, in low to moderately populated areas, their low range limitations render their high capacity
capabilities useless. They are particularly ill suited to rural areas, as their low range abilities would necessitate the construction of an excessive number of cell sites and base stations.

4.2 Proprietary Technologies
Proprietary technologies employ both TDMA and CDMA techniques and were designed specifically for fixed implementations. In many ways therefore, they have better WLL communications qualities than either cordless or cellular technologies. For instance, they offer a wide range of services, including high bit-rates, data in moderately sized coverage areas, and provide excellent voice quality.

4.2.1 Nortel Proximity I
Nortel Proximity I is TDMA based and offers a wide range of services, including 64 Kbps voice and data links. It operates in the 3.4 to 3.6 GHz range using frequency division duplex (FDD), which means that the transmission occurs simultaneously on different frequency channels between the different duplex directions. Each of the TDMA channels can support ten 32 Kbps channels but since DCA is not provided, no more than 32 Kbps per line is attainable. Since each subscriber is provided two lines, 64 (32x2) Kbps is available per subscriber. It has a range of up to 15 kilometers in rural areas.

4.2.2 DCS Airspan
DSC Airspan is CDMA based and can provide data speeds of up to 128 Kbps. It operates in 2 GHz range, and each radio channel is 3.5 MHz wide. It has a range of up to 5 kilometers.

4.3 Cellular Technologies
Although several wireless technologies exist that may find application in the local loop, cellular technologies among them promise to be the most viable solution to the local loop problem developing nations. As a very widely deployed wireless technology, they render themselves as the most likely to be able to take advantage of huge economies of scale and provide universal local access in the most economically efficient means. More than any other wireless form of communication, cellular technologies are very widely
deployed and have been in existence for a considerable amount of time. Consequently, when applied to fixed wireless local loop configurations, they have very good coverage, very high scale economies, and advanced telephony features.

- **Fixed Versus Cellular Implementations**
  Due to the extra functionality imposed by the need to support mobility, fixed cellular systems realize an immeasurable savings in bandwidth. The mobility components HLR, VLR, EIR and AUC are not necessary in a fixed implementation of a cellular network. Thus, a less complex switch replaces the MSC and the mobility components are eliminated from a fixed network since the coordination of handoffs, location updates, and other mobility-related functions is no longer necessary.

Furthermore, in fixed networks, the network and cell planning no longer needs to provide for the inter-cellular overlap that is necessary for handoffs to occur smoothly. In a mobile deployment, cell coverage areas must provide sufficient areas of overlap with neighboring cells in order to allow for continuous communications during handoffs (smooth handoffs).

### 4.3.1 IS-95 CDMA

IS-95-A standard has been developed for a digital cellular system with direct sequence (DS) CDMA technology, operating at 800 MHz band. ANSI J-STD-008 being an up-banded variation of IS-95 is a standard for PCS systems, operating at 1.8-2.0 GHz band. Recently, IS-95-B merges IS-95-A and ANSI J-STD-008.

In DS-CDMA systems, each channel is identified by its unique spreading code. IS-95 based CDMA WLL can support two rate sets. A code channel (that is, a traffic channel) operates at a maximum of 9.6 kbps with the rate set 1 or 14.4 kbps with rate set 2.

IS-95-B offers high-speed data services through code aggregation. In IS-95-B systems, multiple codes (up to eight codes) may be assigned to a connection. Thus, the data rate is a maximum of 76.8 kbps using rate set 1 or 115.2 kbps using rate set 2. Since IS-95-B can be implemented without changing the physical layer of IS-95-A, it is relatively easy for the vendor of IS-95 WLL system to develop the IS-95-B WLL system.

In mobile IS-95 systems, a sectored cell is usually designed with three sectors. As mentioned above, in WLL systems, the antennas for BTS and FSU can be arranged by line-of-sight and this reduces interference from the other user. So, the CDMA WLL cell can be designed with six sectors. This increases the frequency efficiency and the system capacity.
4.3.2 **W-CDMA**
The existing cellular systems (including the second-generation digital systems) have some limitations in supporting high-speed data or multimedia services because of its insufficient maximum data rate per channel. An alternative technology to cope with this problem is the wideband CDMA (W-CDMA). In comparison with the existing narrowband CDMA systems (e.g. IS-95 system with a spreading bandwidth of 1.25 MHz), W-CDMA systems use higher chip rate for direct sequence spread spectrum and, thus, spread its information into wider spectrum bandwidth (typically, equal to or over 5MHz). Thus, data rate per code channel in W-CDMA can be higher than that in narrowband system. Therefore, trying to use W-CDMA systems for WLL application is natural to the second operators, entering the market newly. In this subsection, we explain the W-CDMA WLL services in Korea as an example.

In Korea, the development and the standardization of W-CDMA systems both for mobile service and for WLL service are conducted simultaneously. As a result, several vendors have developed W-CDMA systems according to Korean WLL standard and a second local switching service provider in Korea has a plan to start WLL service with these systems in 2000. The downlink (from BTS to FSU) uses the band from 2.30 to 2.33 GHz and the uplink (from FSU to BTS) uses the band 2.37-2.40 GHz. Thus, the bandwidth of each link is 30 MHz. The spreading bandwidth can be either 5 or 10MHz. For both spreading bandwidth, the information bit rates are 8, 16, 32, 64, and 80 kbps. For the case of 10 MHz spreading bandwidth, 144 kbps of information bit rate is also available.

The WLL standard defines several options for voice codec: 64 kbps PCM (ITU-T G.711), 32 kbps ADPCM (ITU-T G.726), 16 kbps LD-CELP (ITU-T G.728), and 8 kbps conjugate structure algebraic-code-excited linear prediction (CS-ACELP, ITU-T G.729). For packet mode data transmission, some dedicated channels, which are separated from voice channels, are provided. They are the packet access channels in uplink and the packet traffic channels in downlink. Using these channels, packet data services up to 128 kbps are offered. In addition, ISDN BRI is also provided.

- **Comparison of services**
  Most systems offer toll quality voice services and medium- to high-rate data services. The applications being suitable over this data channel are wireless Internet access, mobile computing, and file retrieval services.
DECT seem to be suitable for urban and developed region since they support relatively high-quality channel in the small ranges. On the other hand, the IS-95 CDMA systems being currently used on have higher capacity than TDMA systems and support wider service range per BTS. Thus, CDMA seems to be a more appropriate choice for rural area and for developing regions. In the developed countries, the IS-95 cellular mobile service providers can offer WLL services also, using the same infrastructure. In this case, the fixed WLL service and mobile service can be a bundled service in urban area as mentioned before. As another strategy, the provider may offer the mobile services in urban area and the WLL services in rural area. IS-95-B and W-CDMA systems taking advantages of state of the art technologies can be used in any region, because of their high capacity, wide service range per BTS, and high channel quality. A demerit of these systems is that the technology is not yet proved sufficiently in commercial experiments. However, all the systems discussed in this section cannot offer the local loops for future multimedia services such as video-on-demand. One of the reasons is that these systems are originally based on the mobile systems technologies. We will review another alternative to satisfy these requirements in the next section. For bandwidth hungry services, such as video-telephony or video-on-demand (VOD), the systems mentioned in the previous section are not sufficient. The constraint on capacity per channel can be relieved by migrating to higher frequency ranges and applying broadband wireless systems. In fact, WLL concept in wide-sense contains not only the systems mentioned in previous section but also the microwave multipoint distribution services (MMDS), the local multipoint distribution services (LMDS), the wireless asynchronous transfer mode (WATM), and the satellite access. These considered as a strong candidate for next generation broadband WLL (B-WLL) services.

4.4 Microwave technologies
Microwave technologies were originally designed to provide multi-channel broadband broadcasting of video signals, hence the euphemistic and oxymoronic reference to them as "wireless cable". Initially designed as one way signals, they have recently developed full duplex asymmetric functionality. The main microwave technologies are the US-centric MMDS and LMDS and the European MVDS.
4.4.1 MMDS
Multichannel Multipoint Distribution Service (MMDS) is a microwave system operating in the 2.5 GHz range, it requires line of sight between the transmitter and receiving antenna. Digital signals let MMDS support more channels and also deal better with the topography. Signals can be beamed to a high building, which can serve as one or more cell sites transmitting in various directions. Microwave technology companies such as Spike Technologies have deployed MMDS networks in developing countries like Ghana. The networks boast base stations with a coverage radius of up to 30 miles and speeds of up to 10 Mbps. Yet the cost to subscribers is extremely high, with subscriber stations alone costing US$1200 and base station deployment costs far exceeding those of cellular networks. Thus, only large business clients with the sort of financial wherewithal and data speed requirements that would justify the cost have been targeted.

4.4.2 LMDS
L (Local): The propagation of signals is limited within a single cell.
M (Multipoint): Signals are transmitted in a point-to-multipoint technique.
D (Distribution): Signals distribution which can be: voice, data, Internet, video traffic.
Local Multipoint Distribution Service (LMDS) is also a microwave system that provides two-way transmission in the 28GHz range. Due to the very high frequency range in which it operates, it has very severe line of sight requirements and needs a transmitter every couple of miles. LMDS provides greater upstream bandwidth than MMDS and other wireless services. It is expected to be used for wireless data services and Internet access. LMDS has a range of up to only 5 kilometers and is only really suitable for urban settings. Even more than MMDS, its network and terminal equipment is very costly.

Table II. Comparison of the various technologies Services
<table>
<thead>
<tr>
<th>Service</th>
<th>Cellular</th>
<th>Proprietary</th>
<th>Cordless</th>
<th>Microwave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telephony</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Optimized for data</td>
</tr>
<tr>
<td>Data</td>
<td>14-384 Kbps</td>
<td>144 Kbps</td>
<td>500 Kbps</td>
<td>10 Mbps</td>
</tr>
<tr>
<td>Frequency Band</td>
<td>800/900 MHz</td>
<td>1.5-4 GHz</td>
<td>1.7-2 GHz</td>
<td>2.5/28/40 GHz</td>
</tr>
<tr>
<td>Line of sight</td>
<td>Not critical</td>
<td>Moderately critical</td>
<td>Moderately critical</td>
<td>Very critical</td>
</tr>
<tr>
<td>Supplementary Services</td>
<td>Good</td>
<td>Good</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>Capacity</td>
<td>High</td>
<td>High</td>
<td>Very High</td>
<td>Very High</td>
</tr>
<tr>
<td>Range</td>
<td>High 35 Km</td>
<td>Low 6-15 Km</td>
<td>Very low Km</td>
<td>High 30 Km</td>
</tr>
<tr>
<td>Deployment</td>
<td>Very wide</td>
<td>Limited</td>
<td>Limited</td>
<td>Very limited</td>
</tr>
<tr>
<td>Deployment Cost</td>
<td>Moderate</td>
<td>Expensive</td>
<td>Moderately inexpensive</td>
<td>Very expensive</td>
</tr>
</tbody>
</table>
5. **Key drivers of WLL technology**

**Regulatory mechanism:**
- Licensing: auction and ‘beauty contest’
- License obligations
- Frequency obligations

**Competition and alternatives:**
- Existing loop technology
- ADSL
- Satellite
- Fixed-mobile substitution
- 2G & 3G mobile

**User markets:**
- Region is developed or developing
- Business or residential
- Current & projected service requirements
- Economic growth
Operating parameters

- Population density of services area
- Level of penetration
- Services offered
- Connection cost per line / total life lifecycle cost
- Finance
System requirements:

- Capacity
- Range
- QoS/reliability
- Data requirements
- Frequency band
6. Conclusions
We have investigated the WLL service requirements. In developing countries/regions, the most important requirements are high capacity for voice channels and quick start of services, whereas those in developed countries/regions are high channel quality and advanced (high-speed) data services. Nevertheless, even in the developing countries/regions, the needs for the advanced services will arise with the penetration of POTS. It was shown that PACS and DECT are suitable for developed countries/regions, whereas current IS-95 CDMA system is more appropriate in developing ones. On the other hand, IS-95-B and W-CDMA systems taking advantages of state of the art technologies can be used in any region, because of their high capacity, wide service range per BTS, and high channel quality, but the demerit of these systems is that the technology is not yet proved sufficiently in commercial experiments. To compete with wireline services using DSL, the broadband WLL system supporting multimedia services should be developed. From this point of view, the strongest candidate for B-WLL system currently is LMDS. LMDS can offer the WLL services such as video telephony, VOD, and high-speed Internet access. In conclusion, it is expected that WLL will play a more important role for local loop services in future.