The importance of in-building solutions in third-generation networks

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Providing good in-building coverage plays an important role in attracting and retaining mobile subscribers. Ordinarily, coverage from the macro network extends into buildings but should be complemented by dedicated in-building systems. Greater data capacity and the ability of third-generation networks to provide high-speed data services increase the demands put on the cellular network. Subscribers have great expectations regarding third-generation services. Therefore, when introduced, the new services must (at very least) be available everywhere second-generation services can be found. Notwithstanding, many third-generation networks deployed to date have been designed primarily to provide good coverage in outdoor environments—not inside buildings. As a consequence, users of early implementations of wideband code-division multiple access (WCDMA) rate third-generation services poorly compared to second-generation services.

Besides guaranteeing better quality of service (QoS), dedicated in-building systems enable operators to catch roaming subscribers—most roaming subscribers have automatic public land mobile network (PLMN) selection, which means that if the regular connection is lost, their phone automatically selects the best available PLMN. Operators who provide dedicated in-building coverage in key locations, such as airports and train stations, can thus catch these high-value roaming subscribers.

The implementation of dedicated in-building coverage in CDMA-based networks also offloads the macro system, thereby increasing overall system capacity. In other words, operators can, with minimum investment, continue to use existing networks to serve a growing number of subscribers. This gain in capacity means that operators can put off splitting cells and thereby substantially reduce costs of network expansion. In particular, it is more beneficial to deploy dedicated in-building coverage systems in third-generation CDMA-based networks than in time-division multiple access (TDMA) networks.

Interesting solutions for deploying in-building coverage in WCDMA networks make use of distributed radio base stations (DRS) and passive distributed antenna systems (DAS). These solutions reduce overall costs by lowering transmission costs, increasing trunking gain, and by sharing RBS equipment.

BOX A, TERMS AND ABBREVIATIONS

2G	Second-generation
3G	Third-generation
CDMA	Code-division multiple access
DAS	Distributed antenna system
DRS	Distributed radio base station
GSM	Global system for mobile communication
HSDPA	High-speed data packet access
PLMN	Public land mobile network
RAN	Radio access network
RBS	Radio base station
RF	Radio frequency
TDMA	Time-division mobile network
UE	User equipment
WCDMA	Wideband CDMA
WLAN	Wireless local area network

Comparing 3G and 2G

There are several reasons why the demand for dedicated in-building coverage is greater in WCDMA networks than in current second-generation networks:

- Less favorable link-budget, especially for high-bit-rate services, because WCDMA networks use higher frequencies than most second-generation networks, the indoor coverage from macro cells is often inferior due to greater link loss. In addition, greater capacity must be provided for WCDMA than for second-generation systems because stronger signal strength is needed for high-bit-rate services.
- End-users expect better quality of service from third-generation mobile networks—a key differentiator of third-generation mobile networks is high bit rates, but most high-bit-rate services will be used by end-users who are stationary; that is, the majority of end-users will be indoors in cafés, restaurants, offices, hotels, shopping centers, bars, pubs, subways, gyms, train stations, airports, and homes. Few people remain stationary while outdoors because conditions are seldom ideal (too hot, cold, wet or windy). To attract new subscribers, operators of third-generation mobile networks should, at very least, provide the same level of coverage as end-users have come to expect from existing second-generation networks. To provide this level of coverage, operators can employ dedicated inbuilding coverage in key locations.
- Dedicated in-building coverage helps offload the macro network. This has a twofold effect: (a) dedicated in-building systems offload the macro cells by reducing average downlink power levels, which in turn, releases additional system capacity for the outdoor cell; and (b) in-building cells are isolated from the macro network, which results in lower interference levels. In-building cells can thus provide greater capacity than outdoor cells.

Coverage vs. capacity in CDMA-based systems

In TDMA systems, cell coverage and capacity are more or less independent. Coverage depends on such factors as radio frequency (RF) power, sensitivity and interference. Capacity, on the other hand, is determined by the number of channels provided.

By contrast, in CDMA and WCDMA systems, capacity and coverage in the downlink are highly interdependent (Figure 1). In CDMA systems, multiple users share the same base station transmitter, and thus the same power resource in the downlink (Figure 2). As a consequence, the total cell capacity is affected by path loss to each user. Greater path loss is compensated for by a comparably larger portion of the downlink resource, which leaves less of the downlink resource for other users. In essence, the system can handle more users at low power than at high power.

Path loss is determined by a user's location in the cell. It is also greatly influenced

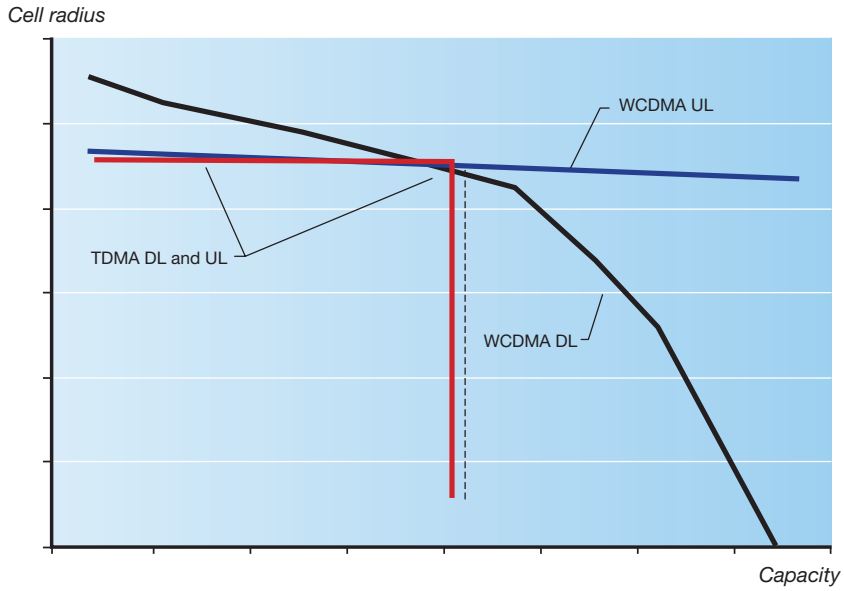

Figure 1
Dependency of coverage (WCDMA) in the uplink and downlink compared to TDMA.

by whether the user is outdoors or indoors. Users located outdoors and close to the center of the cell have the least path loss; users who are inside buildings far from the center of the cell (cell border) have the greatest path loss. Users inside buildings consume a proportionately larger share of the downlink resource, especially when located close to the cell border. Note also that a larger number of users (indoors and outdoors) is almost always located closer to the cell border (high path loss) than to the cell center (Figure 3).

Indoor "black holes"

Ordinarily, a well-designed WCDMA system limits the maximum downlink power to any given user. A typical limit is 20% of total available power. Therefore, in a worst-case scenario with users in buildings in less-than-ideal locations, a cell can serve only a few users.

Uplink vs. downlink

Conditions in the uplink are somewhat different from those in the downlink. Because each user has his or her own dedicated radio resource (user equipment, UE) in the uplink, capacity and coverage are not directly interdependent except for the effect of noise, which has an increasingly negative effect as the number of users in the cell grows. Even so, dedicated in-building systems also offer specific benefits to the uplink. For instance,

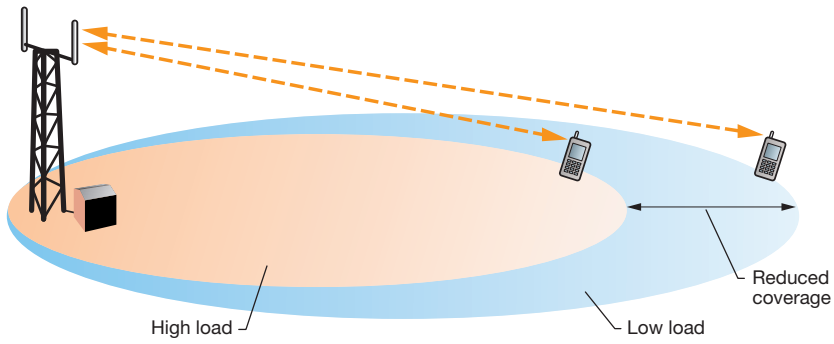

Figure 2
Dependency of coverage and capacity (load) in CDMA-based systems.

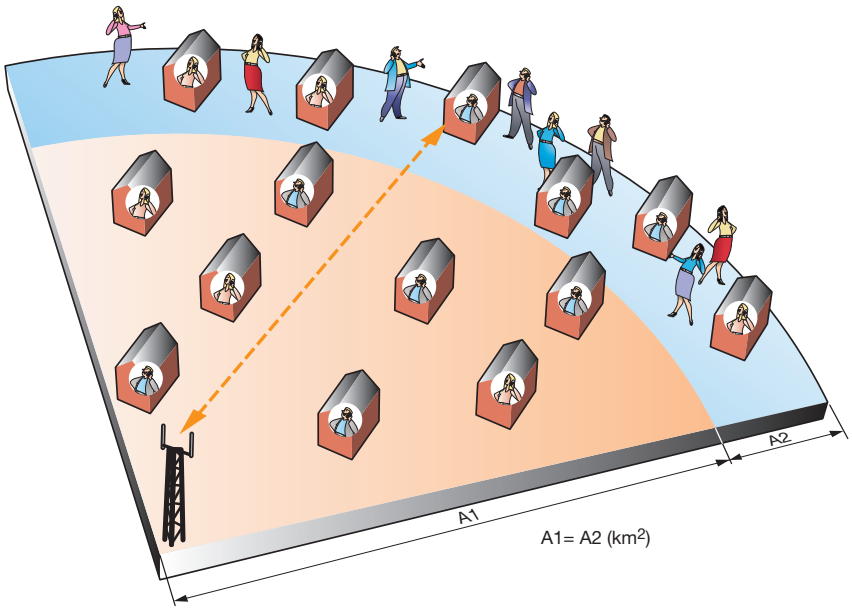

Figure 3
Areas A1 and A2 are equal and contain the same number of subscribers, but average path loss to users in area A2 is much greater than for users in area A1.

less interference from other cells, which means that an isolated indoor cell can have greater capacity in the uplink than an outdoor macro cell.

By design, traffic is not expected to be balanced in the uplink and downlink. The majority of high-speed data traffic occurs in the downlink. Therefore, most indoor cells are limited by the capacity of the downlink.

High bit rates require more power

The services offered in WCDMA systems determine the power levels required by the uplink and downlink. High-bit-rate services require greater power levels from the RBS and mobile equipment than low-bit-rate services. Also, bear in mind that most

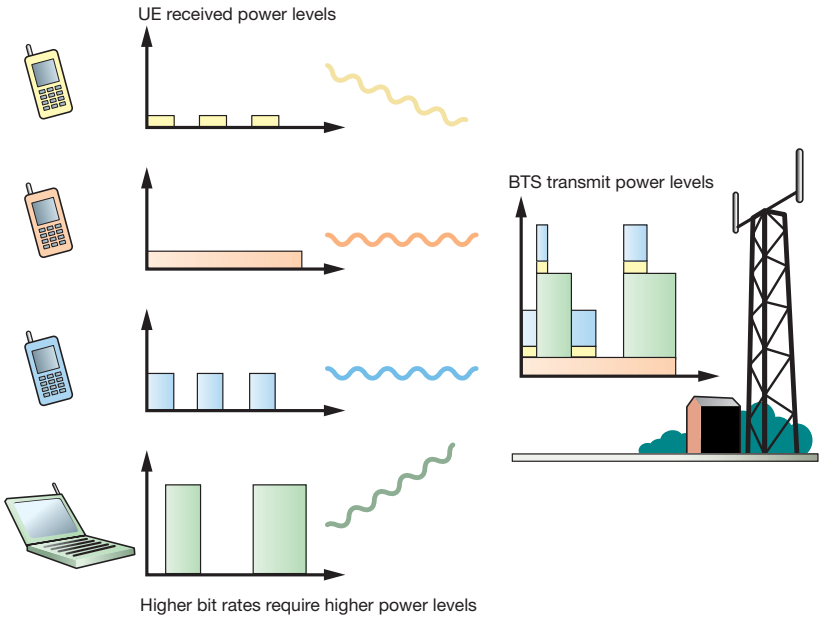

Figure 4
Higher bit rates require higher power levels

high-bit-rate services are used by stationary users in indoor environments.

Offloading the macro cell

If most or all indoor users in a cell are served by dedicated indoor systems, then less average power is required to serve all remaining users in the macro cell. And as we have seen, less power per user means that a larger number of users can be served.

The actual gain in capacity depends on where in the cell the indoor users are located. The greatest benefits can be derived from introducing dedicated in-building systems for users with high path loss—that is, for users in buildings close to the cell border.

Isolated indoor cells yield greater capacity per cell

Cell capacity in CDMA-based systems is dependent on

- the power needed to serve each user in the cell; and
- interference from other cells—less interference means greater capacity.

Minimum interference is achieved by isolating cells from one another. Walls and other structures help isolate dedicated indoor cells, making them less vulnerable to interference from signals from other cells. Ortogonality is also better in indoor systems. The capacity of dedicated indoor cells is thus typically two to three times greater than that of an ordinary non-isolated macro cell. Indoor cells that do not employ soft handover to other cells have even greater capacity.

Potential capacity gains

Figure 5 shows a model for describing gains in capacity. According to this model, the addition of in-building systems has the potential to increase network capacity up to 400 percent. Moreover, cost per subscriber, including the cost of the in-building system, can be reduced 67%.

In the first case, macro cells provide coverage for outdoor and indoor users (12 outdoor users and 6 indoor users, Figure 5). Average path loss to each user is high, and as a consequence, total capacity is relatively low.

In the second case, the indoor users enjoy dedicated coverage. The coverage from macro cells is used mostly by outdoor users. Average path loss per user is thus less, and the capacity of each macro cell has increased, which means the macro cells can serve more users. The addition of a dedicated cell for indoor users also increases available capacity indoors, because the indoor cell is isolated from the macro cells. The capacity of the indoor cell is thus greater than that of the outdoor cells.

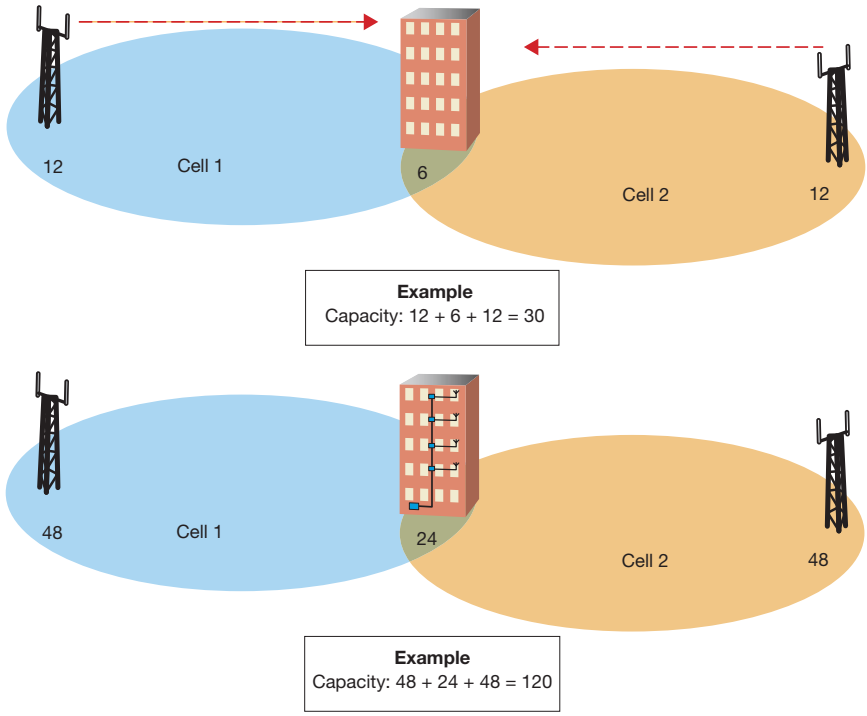

Figure 5
The deployment of dedicated in-building systems can increase total network capacity up to 400%.

The gain in capacity signifies that the network can handle a larger number of subscribers. Compared to traditional methods, such as cell splitting or increasing the number of frequency channels, the addition of dedicated in-building coverage is thus a cost-effective way of catering for new subscribers.

The actual gain in capacity depends on factors such as number of indoor users served by dedicated in-building coverage, location of users and buildings, the traffic profile, and penetration loss due to building walls and structures. In many cases, the capacity gain is considerable. Theoretical calculations show that capacity in certain parts of a cellular network can increase by 200-600% provided some indoor users are served by dedicated cells. Measurements in live net-

works have confirmed considerable gains in capacity.

Benefits to networks with high load in the downlink

During initial rollout, system load is usually light and coverage in the uplink and downlink is more or less balanced. The benefits of offloading macro cells via dedicated in-building systems are thus negligible. However, as load increases and the system becomes increasingly limited by the downlink, the benefit of dedicated in-building coverage increases.

In-building coverage flattens load peaks

In systems that lack dedicated in-building coverage, path loss to different users can vary considerably depending on user location and whether the user is located indoors or not. This variation in path loss means that system capacity fluctuates according to user distribution. Operators need to consider this aspect and allocate sufficient margins when planning their networks. But if indoor users are served via dedicated indoor cells, there will be less fluctuation in capacity, and operators can allocate smaller margins when planning their networks.

HSDPA

High-speed-data packet access (HSDPA) is a method of transmitting very high data rates in a WCDMA network. The theoretical maximum data capacity from HSDPA is 14.4Mbps peak and approximately 2Mbps average (shared by all users in a cell).

The interdependent relationship between coverage and capacity described above also holds true for HSDPA, because throughput to each user is dependent on radio link quality. That is, total data throughput suffers when several simultaneous users are located in an area with poor radio-link quality. Therefore, one could say that WCDMA networks with HSDPA will benefit from dedicated in-building coverage, because it ensures that more users can enjoy high data throughput.

CDMA vs. WCDMA

Everything described thus far is valid both for WCDMA and narrowband CDMA-based systems, such as CDMA2000 and IS-95. With respect to indoor coverage, however, narrowband CDMA systems do differ from WCDMA systems in that they use narrower bandwidth for each radio channel. As a consequence, it is easier to set aside a few of these channels for indoor coverage and thereby offload the channels used for outdoor coverage. By reserving some available channels for indoor coverage, the in-building system needs not dominate over signals from the macro network. This is otherwise a problem for operators who implement dedicated in-building coverage for WCDMA—it is thus impractical to set aside channels for this purpose (especially if the operator has only a few WCDMA channels).

Distributed antenna systems

A distributed antenna system (DAS) is a network of antennas distributed throughout a building to provide dedicated in-building coverage. The system can be passive or active. A passive DAS consists of a network of coaxial cables, couplers, and power splitters that distribute RF signals to antennas placed throughout the building. One variant of a passive DAS employs radiating coaxial cables instead of discrete antennas. The decision to use discrete antennas or radiating cables is usually based on factors such as building structure and installation constraints.

Ordinarily, an active DAS uses optical distribution—the RF signals from the RBS are converted into optical signals by a local interface unit. The optical signals are distributed through the building via optical cables to several remote units where they are converted back into RF signals. Antennas or small coaxial distribution networks are connected to each remote unit to provide coverage on each floor.

There are many advantages to a passive DAS compared to an active DAS. For instance, it offers low initial cost and high reliability. Being a wideband system, the passive DAS solution is also ideal for multi-operator and multi-service systems, including all kinds of radio-based services, such as trunked radio, cellular systems, and wireless local area networks (WLAN) up to 2.5GHz. The majority of today's installations of in-building systems are passive DAS solutions.

Benefits of DAS

The DAS gives operators a more effective solution to providing in-building coverage

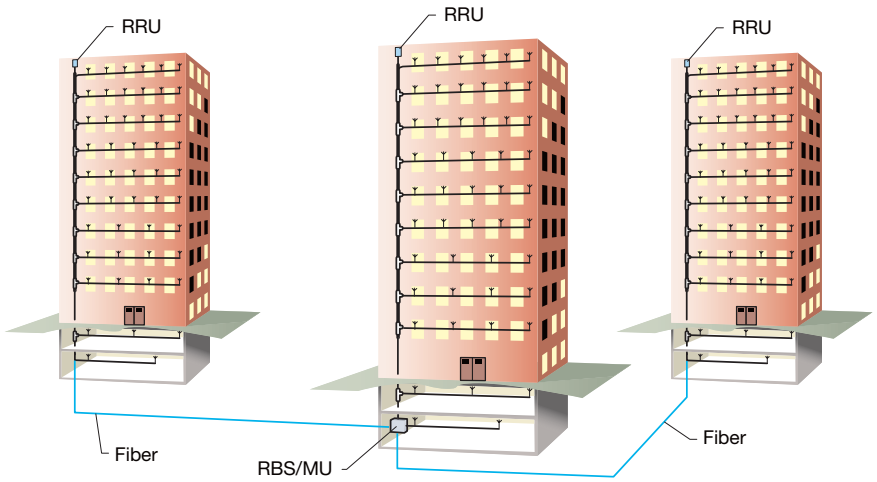

Figure 6
DRS solution using RBS 3402 Main-Remote.

than small, distributed indoor base stations (pico RBS). For instance, it provides trunking gains on the radio interface and transmission links—every radio channel is thus instantly available in every part of the building; this, in turn, increases spectrum efficiency and makes it possible to cater for local traffic peaks. The RBS needs only one transmission line to feed an entire building. This makes for a high degree of transmission trunking efficiency and decreases the amount of transmission overhead that is normally transmitted to each RBS.

DAS solutions also make it is easy for operators to control and confine coverage within a building and to reduce interference to and from the macro network, which increases overall network capacity.

DRS solution

A distributed RBS solution (DRS) is an interesting solution for implementing in-building coverage for WCDMA (Figure 6). The solution shares one RBS between several buildings or indoor areas. The RBS is connected to an optical distribution system that converts radio signals into optical signals before distributing them to each building over optical fiber. High-power optical remote units in each building convert the optical signals back into RF signals. The signals are then distributed inside the building via a coaxial antenna network. Some of the benefits of deploying DRS configurations are greater capacity thanks to improved trunking, low transmission cost, and low investment in the radio access network.

Greater capacity

Trunking gain refers to an increase in number of channels (or bandwidth), or in other words, an increase in capacity. The DRS solution provides trunking gains for radio interface and transmission—spectrum efficiency improves because every radio channel is instantly available in each associated building. Moreover, the full capacity of the RBS can be made available for any building or site, making it easier for operators to handle local peak loads (for example at restaurants during the lunch hour or when users seek indoor shelter from sudden rain showers).

Low transmission cost

Operators can use statistical multiplexing to reduce transmission costs—many users share the same transmission, which is concentrated to one site. In many markets, dark fiber is inexpensive, making the overall cost for a DRS solution favorable compared to other alternatives.

Low RAN investment

The macro site and the dedicated in-building site share the macro RBS. Operator investments in the radio access network are thus lower than investments in comparable alternatives. Ericsson's RBS 3402 Main-Remote is an ideal choice for this application.

Capacity—the way forward

Given the benefits to WCDMA networks, it can be argued that dedicated in-building coverage should be introduced early in the evolution of 3G systems. The traditional network evolution of second-generation systems, such as GSM, can be described as follows:

1. Initial roll-out and coverage.
2. Cell split, shorter site-to-site distance.
3. New spectrum.
4. Micro cells, in-building cells.

Today, however, early measures are taken to combat interference. The current network evolution is thus:

1. Initial roll-out and coverage.
2. Tight frequency reuse (MRP, FLP).
3. New spectrum.
4. Micro cells, in-building cells.
5. Cell split, shorter site-to-site distance.

The idea is to introduce network features that reduce interference instead of splitting cells, which at very least, doubles site costs.

Early introduction for WCDMA

For WCDMA—to capitalize on the benefits of offloading the macro cell network—it pays to deploy dedicated in-building coverage at an earlier stage than was done in second-generation systems. In most cases, the initial roll-out is planned to provide voice and high-speed data services to outdoor users. Indoor coverage is generally quite limited and mostly consists of voice services. High-speed data services are usually only available in buildings close to the center of the cell. Users generally perceive in-building coverage to be weaker than that from existing second-generation networks.

Plans to offer comprehensive, in-building, high-speed data coverage from the initial roll-out of the macro network are not feasible or practical due to the number of sites that would be necessary.

Ordinarily, operators plan the initial network roll-out to handle relatively light loads, because this approach yields the most performance for the least cost. But as system load increases, the downlink quickly becomes a limiting factor, and breaks or holes in coverage occur during peaks in traffic. In dense urban areas, in particular, there is considerable risk that a temporary concentration of indoor users in one or more cells could severely limit the capacity of those cells. Operators should thus take some kind of action to reduce load and improve coverage. Some of their alternatives include

- adding new sites and splitting cells;
- adding new frequencies; or
- offloading the macro network by introducing dedicated in-building coverage for indoor hot-spots.

Each of these alternatives achieves the same goal of reducing system load and maintaining coverage, but the associated costs vary considerably. Splitting cells is the most costly alternative because of the need for new sites. Adding new frequencies, or introducing a second carrier, provides greater capacity, but still does not guarantee adequate in-building coverage. In urban areas, where the majority of users are located indoors, the implementation of dedicated in-building systems can be a cost-effective method of dealing with increased load. In summary, the preferred evolution of WCDMA networks is as follows:

1. Initial roll-out and coverage.
2. Indoor coverage introduced to offload macro cells and to cover indoor hot-spots.
3. Additional carriers (new spectrum).
4. Cell split, micro-cells.

The main idea is to keep costs down by waiting as long as possible to split cells.

Primary targets

To realize maximum benefit, operators should first target heavily populated buildings and underground areas that are close to

cell borders. Underground shopping centers and other underground areas close to the cell center might also be priority targets if users in these areas experience substantial path loss from the macro cell.

Other obvious targets include buildings whose capacity requirements exceed the capabilities of a single macro cell. In cases like this, an in-building system is justifiable regardless of where the building is located. Moreover, the in-building system can be split into several cells to provide as much capacity as needed. Typical examples include airports, skyscrapers, conference centers, shopping centers, and sports stadiums.

Market experience

Japan

In Japan, the first country to introduce WCDMA, NTT DoCoMo is investing heavily in in-building coverage—it plans to have implemented more than 3000 in-building sites by March 31, 2005, and an additional 2000 sites by March 31, 2006.

Vodafone Japan has seen a slow increase in subscribers due to a shortage of competitive terminals. Notwithstanding, the operator acknowledges the importance of dedicated in-building coverage and plans to implement 1000 in-building sites before year-end (fiscal year) 2004. The majority of these will be single-operator sites, because operators in Japan still compete by providing coverage.

KDDI, which operates a CDMA2000 system at 800 MHz and has plans to introduce services at 2GHz, is also implementing large-scale, dedicated in-building coverage.

Besides single-operator, in-building sites, numerous multi-operator systems have been installed throughout Japan in railway and subway stations and in underground shopping centers. The Japanese Ministries of Post and Telecommunications and of Construction have subsidized these installations to help guarantee coverage in the event of a major accident or natural catastrophe, such as an earthquake. The sites for second-generation services (approximately 600) are now also being complemented with coverage for WCDMA.

Spain

Operators in Spain recognize that good in-building coverage plays a big role in attracting and retaining subscribers. The primary goal is to complement current second-generation dedicated in-building systems with third-generation coverage and to implement new coverage in key locations.

Sweden

Operators in Sweden also recognize the benefits of dedicated in-building coverage and are looking for cost-effective solutions. Some have already implemented distributed antenna systems using macro RBSs.

Conclusion

Operators cannot ignore the importance and advantages of providing dedicated in-building coverage in third-generation networks. Users who try new third-generation services expect them to exceed existing (second-generation) services in every respect. This is especially true for in-building coverage. As a consequence, operators want dedicated in-building coverage systems in third-generation networks to complement the existing macro network.

Besides providing excellent local in-building coverage, dedicated in-building systems for third-generation CDMA-based networks greatly offload the part of the macro network. Therefore, they give operators a cost-effective way of catering for new subscriber growth.

In all likelihood, distributed antenna systems will dominate as the preferred solution for providing in-building coverage. New solutions, such as the distributed RBS solution, are also of interest thanks to overall lower costs—lower transmission cost, greater trunking gain, and the ability to share RBS equipment.

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