Ericsson's GSM RAN capacity solutions

Peter Blom

High-capacity solutions are about building high-capacity networks in the most economical way, and therefore, GSM radio network capacity solutions are becoming increasingly important. Radio network capacity solutions can be divided into three categories: cell capacity, network capacity, and channel capacity.

The author discusses various solutions for improving radio network capacity in each of these areas. He also describes different implementations and recommends three general steps for introducing solutions in the network.

Capacity solutions for GSM radio access networks continue to be in focus. In the Americas, non-GSM technologies, such as TDMA and AMPS, occupy a substantial amount of spectrum. Likewise, competition makes it difficult for operators to acquire new spectrum. Therefore, operators who migrate to GSM are faced with the challenge of providing enough capacity for new services while maintaining capacity in legacy systems. The downturn in the world economy has also put constraints on operators, forcing them to maximize benefits from every investment. Since high-capacity solutions are about building high-capacity networks in the most economical way, GSM radio network capacity solutions are perhaps more important today than ever before.

Radio network capacity solutions can be divided into three solution categories:

- cell capacity solutions—these solutions consist of methods and features that permit more transceivers per cell;
- network capacity solutions—these solutions focus on adding different kinds of cells and on making the most of cell capacity by distributing traffic as efficiently as possible; and
- channel capacity solutions—these solutions center on ways of using the available throughput of the channels in the air in a more efficient manner, for example half-rate voice channels and GPRS.

Cell capacity

The one factor that has the greatest influence on cell capacity is frequency reuse. Cell capacity is thus determined by different methods and functions to enhance frequency reuse. Two common methods are

- multiple reuse pattern (MRP); and
- fractional load planning (FLP).

The multiple reuse pattern, which is based on baseband frequency hopping, yields the best results for networks composed mainly of filter combiners. The primary transceiver carries the broadcast control channel (BCCH) and must therefore have a relatively loose reuse pattern (explanation: a handset must listen to the information broadcast on the BCCH before it can make calls in a cell). But thanks to the frequency hopping gain, all remaining transceivers in the network can have a successively tighter reuse pattern. Compared to a non-hopping network, the MRP solution can more than double cell capacity. The drawbacks of MRP are that it requires

- considerable spectrum (greater than 7 MHz); and
- at least three transceivers per cell for good performance.

Fractional load planning is based on synthesized frequency hopping, which requires the use of hybrid combiners. In FLP, the gain from frequency hopping is not dependent on the number of transceivers in a cell, since each transceiver can hop on every frequency allocated to the cell. Notwithstanding, due to the characteristics of synthesized frequency hopping, the BCCH transceiver cannot hop frequencies. Ordinarily, to guarantee adequate voice quality for a non-hopping traffic channel (TCH), a frequency reuse of approximately 15-18 is needed. But by using the BCCH in an overlaid subcell feature, it is possible to plan BCCH frequency reuse as if the BCCH transceiver could hop frequencies, making a frequency reuse of approximately 11-12 feasible. The most common FLP methods in use are 1/3 and 1/1, and FLP can be implemented in frequency bands as narrow as 3 MHz.

BOX A, TERMS AND ABBREVIATIONS

AMPS	Advanced mobile phone system	HR	Half-rate
AMR	Adaptive multirate	IRC	Interference rejection combining
BCCH	Broadcast control channel	MAIO	Mobile allocation index offset
DTX	Discontinuous transmission	MRP	Multiple reuse pattern
EDGE	Enhanced data rates for global evolution	PCCCH	Packet-data common control channel
EFR	Enhanced full-rate	QoS	Quality of service
FAS	Frequency allocation support	RBS	Radio base station
FLP	Fractional load planning	TCH	Traffic channel
FR	Full-rate	TDMA	Time-division multiple access
GPRS	General packet radio service	TET	Traffic estimation tool
GPS	Global positioning system	WCDMA	Wideband code-division multiple access
GSM	Global system for mobile communication		

A third method, known as non-uniform frequency planning, can be a mix of MRP and FLP, or a totally free allocation of frequencies. Since this method is more complex, cell-planning and measurement tools are recommended, such as TEMS Cell Planner and frequency allocation support (FAS).

Ericsson's GSM system provides a host of features that minimize frequency reuse and maximize cell capacity. The most basic feature—frequency hopping—is unique to GSM and is the basis for all tight frequency reuse solutions. Since a cell can accommodate up to 16 different hopping or non-hopping frequency groups (channel groups), there is considerable inherent flexibility for adapting the network to different services with different requirements for radio quality. Radio base station (RBS) site synchronization and mobile allocation index offset (MAIO) management are provided to maximize the benefits of FLP. MAIO is the parameter that determines when a frequency is used in a cell that employs FLP. With proper MAIO planning it is possible to minimize or even eliminate interference between synchronized cells.

Similarly, quality-based dynamic power control and discontinuous transmission (DTX) are employed to minimize radio interference. The quality-based power control feature performs very well in networks that employ tight frequency reuse—it provides a substantial decrease in output power, especially compared to non-quality-based algorithms. Should quality-related problems persist, an intra-cell handover function finds a new channel in the cell on which the call can continue.

In addition, the dynamic overlaid/underlaid subcells feature divides the cell into two subcells with traffic management functionality between them. It also makes it possible to restrict the coverage of the overlaid subcell, thereby facilitating even tighter reuse in it. And finally, there is the adaptive multirate (AMR) voice codec for GSM full-rate channels. The feature uses several voice codecs and associated error protection (channel coding) to adapt to the quality of the radio environment. Compared to the full-rate (FR) and extended full-rate (EFR) voice codecs, this feature greatly improves robustness. In fact, compared to EFR, when AMR full-rate is used to its fullest extent—to tighten frequency reuse and to add more transceivers—the traffic capacity in the cell can be doubled.

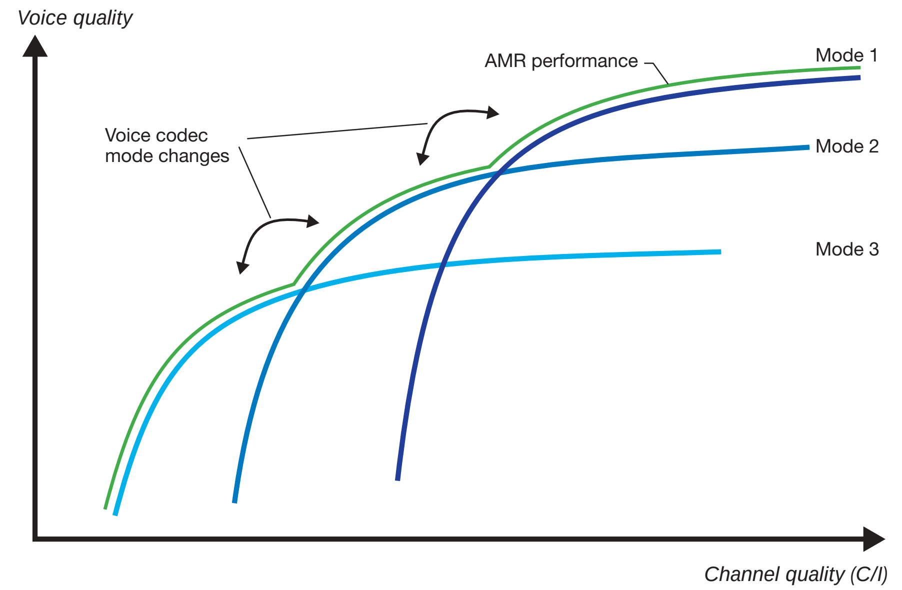


Figure 1
The principles of AMR. Voice quality is maximized by adapting—or by switching between several voice codecs—to the quality of the radio channel.

Network capacity

In addition to improving cell capacity, operators can introduce micro cells, since site acquisition for micro cells is usually easier and less expensive than when adding regular cells. To facilitate the deployment of micro cells, Ericsson provides the traffic estimation tool (TET), which enables operators to identify the optimal site location. And since it is possible to measure the amount of traffic a certain site location will carry, he can then calculate time to payback before the operator installs the base station.

A multiband network option is open to operators who have frequencies in a second frequency band. The amount of capacity that can be derived from implementing cells in a second frequency band depends on the amount of spectrum in the alternative frequency band. Even so, since the cell capacity solutions described above can be applied in any frequency band, the extra capacity is never negligible. To derive the optimum cost-benefit ratio, Ericsson recommends that the operator reuse all existing sites for RBSs that belong to the new frequency band.

Traffic management is an important issue in a network composed of cells of different

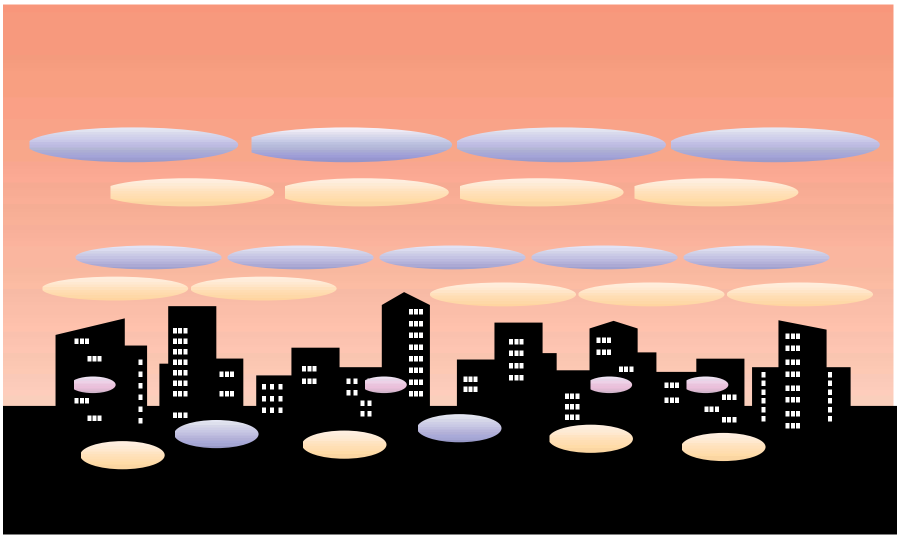


Figure 2
Network capacity: Efficient traffic-management features, such as Ericsson's multilayered hierarchical cell structure (HCS), should be employed when different kinds of cells and frequency bands are used.

sizes and frequency bands. Intelligent traffic distribution algorithms let cells cooperate and help one another to enhance network capacity to a degree that exceeds the sum of all individual cells.

With multilayered hierarchical cell structures—the most important traffic-handling function in Ericsson's GSM system—cells can be divided in up to eight layers, and traffic can be prioritized and distributed between these layers. There are also numerous add-on functions, such as

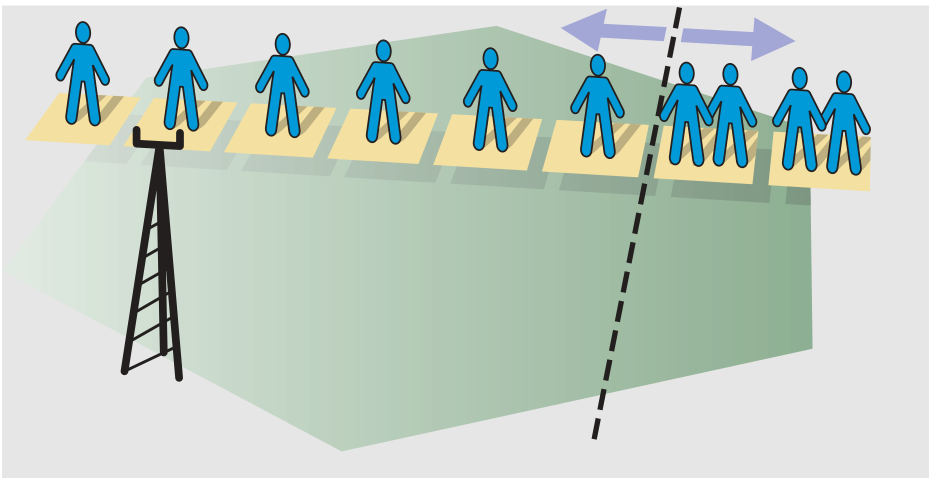
- *cell load sharing*, which distributes traffic within layers;
- *assignment to another cell*, which redirects traffic to other cells when congestion occurs during call setup; and
- *handling of fast-moving mobiles*, which moves calls to higher layers when there are too many handovers within a given interval. This function reduces the number of handovers, thereby increasing voice quality and reducing processor load.

Channel capacity

In the context of circuit-switched traffic, channel capacity is about half-rate voice channels and the way they are managed. Since the half-rate technique reduces the quality of voice, it has not been widely deployed. However, operators are now beginning to use this technique more and more, since it can be allocated on a dynamic basis (dynamic HR allocation) during traffic peaks.

In the context of data communications, GPRS is a channel capacity solution. It makes optimum use of channels and maximizes capacity by allowing several users to share the same channels. Ericsson's GPRS solution provides dedicated as well as on-demand packet-data channels. The solution also supports dedicated packet-data common control channels (PCCCH). During 2002, numerous improvements will be made available, including EDGE and

Figure 3
Dynamic half-rate allocation: To mitigate the impact on voice quality, half-rate techniques should only be used during traffic peaks.



quality-of-service-based (QoS) scheduling. EDGE technology, which can more than triple throughput per channel, enhances packet data capacity and facilitates a multitude of new services that require extra bandwidth. The QoS scheduling functions allow operators to differentiate their service offering to distinct user segments.

Capacity gains

Figure 4 compares the most common options for improving network capacity. As can be seen, most of the methods have the potential to double network capacity, and our recommendation is that the operator should implement or apply as many of these as possible. In particular, two solutions really stand out: AMR full-rate, and micro cells. Note: To derive the greatest gains from AMR full-rate, the penetration of AMR handsets must be high.

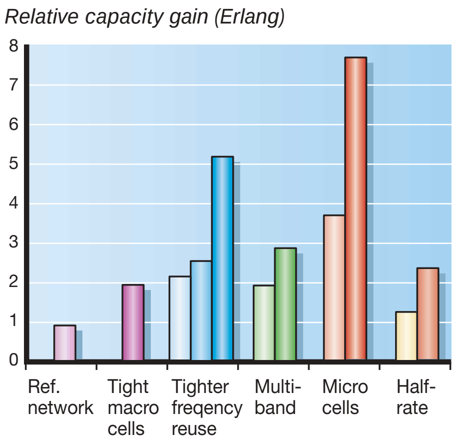


Figure 4
Reference network: Average network without frequency hopping.
Tight macro cells: Double the number of macro cells.
Tighter frequency reuse: (a) MRP network based on EFR; (b) FLP 1/1 network based on EFR; (c) FLP 1/1 network based on AMR.
Multiband: (a) 50% penetration of capable terminals; and (b) 100% penetration of capable terminals.
Micro cells: One micro cell every 200 m. (a) 2 TRX per micro cell; (b) 4 TRX per micro cell.
Half-rate: (a) 25% penetration of capable terminals; (b) 100% penetration of capable terminals.

Implementation aspects

Apart from gains in capacity, the two main parameters that an operator should consider when building a network are monetary cost and time—the actual cost of each solution is market-dependent, since the costs associated with cell sites (site acquisition, site preparation, rental costs) and transmission vary from market to market.

In every market it costs time and money to build sites. Accordingly, the greater the number of sites required, the higher the cost. When viewed in this light, we can conclude that tight frequency reuse offers the most expedient and cost-effective solution to improving capacity, since in many cases the operator needs only add transceivers to existing cabinets.

If the operator wants to maximize his use of existing sites then the second-best option is to deploy transceivers on other available frequency bands. In this case, the operator needs only add cabinets at sites where extra capacity is wanted.

A third option is to introduce micro cells—thanks to the small size of micro base stations, it is easier and less expensive to acquire sites for them.

A final option is to build more sites.

As mentioned above, the operator might also make use of half-rate channels, but since this option decreases voice quality, it should be allocated dynamically (dynamic HR allocation), and then mostly as a last-resort option when network expansion through other means cannot keep pace with growth in traffic. The half-rate technique can be deployed very quickly by activating various software features.

Recommended way of increasing capacity

Taking into account the potential for capacity and the implementation aspects for

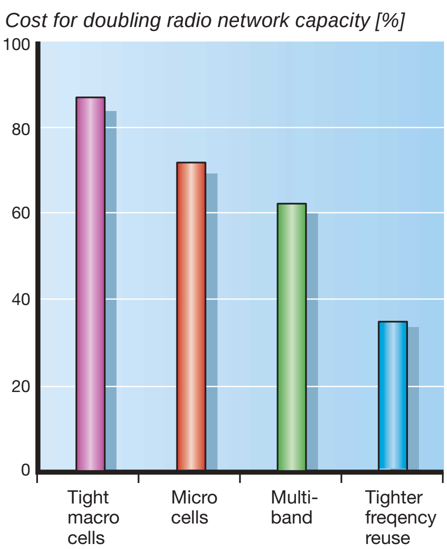


Figure 5
Cost comparison: The additional cost of doubling radio network capacity using various solutions relative to the original investment.

Figure 6
Micro base station RBS 2302.

each capacity-boosting solution, we can recommend a general order for introducing the different solutions in the network.

Step 1

Operators should activate frequency hopping and implement one of the tighter frequency reuse methods. Which method should be used depends on factors such as RBS hardware, amount of spectrum, and cell plan. Additional reuse-enhancing features might also be necessary depending on the reuse method and the degree of frequency use.

Operators should activate AMR. Although the initial gain in capacity is small, a significant improvement in quality can be achieved for users with AMR-capable terminals. As the penetration of AMR handsets increases it will allow more transceivers to be deployed in the network, gradually enhancing traffic capacity.

Step 2

Operators who have access to spectrum in other frequency bands should start deploying equipment to use those frequencies. Costs can be kept to a minimum if operators reuse existing sites.

Operators can add micro cells or indoor cells at traffic hot-spots, which include popular squares, conference centers, shopping malls and airports. The use of micro cells to cover hot-spots will offload the macro cells, and help operators to avoid the cost of having to split cells.

Operators can also use dynamic half-rate allocation to avoid congestion at peak traffic. This measure reduces the pressure on operators to build out the network, allowing them to build it out at a manageable pace.

Step 3

As traffic increases, the number of micro cells and indoor cells will also continue to grow. At some point, the micro cell layer will be almost contiguous. By adding more capacity to the micro cells and indoor cells, operators can achieve an extreme boost in capacity.

Future GSM RAN capacity solutions

GSM has been in commercial operation for some 10 years now, but there is still ample room for enhancing capacity. One area that shows great potential is the use of advanced interference-suppression algorithms. In the base station, we will see this type of algorithm introduced in the form of interference rejection combining (IRC). The interference-suppression performance of this feature far outperforms present-day receiver algorithms. Simulations show that IRC can give link gains of up to 5 dB in non-synchronized networks, and up to double that in synchronized networks. This can be translated into better voice quality and data throughput on the uplink. However, due to a lack of corresponding functionality in present-day handsets, the gain in capacity will be limited. To remedy this situation Ericsson is also researching interference suppression algorithms for terminals. Limited processing capacity, small size, and the importance of design (for example, only one antenna) impose harsh restrictions on algorithms. However, Ericsson has made some technological breakthroughs and expects to introduce powerful interference-suppression algorithms in handsets in the next few years.

Apart from boosting IRC performance, synchronized radio networks also enhance capacity. Synchronization is achieved by synchronizing all RBS sites to the GPS system. When all cells are synchronized to the same reference clock, interference planning will no longer be limited to cells located at the same site. Instead, operators will be able to determine which cells truly interfere with each other, no matter where they are located. Here, too, simulations show gains of up to 20% compared to a site-synchronized network.

AMR technology will also enhance the channel capacity solution for half-rate channels: AMR half-rate consists of a subset of the AMR voice codecs defined for full-rate channels. As with AMR full-rate, it adapts, by switching between voice codecs, to the quality of the radio environment. AMR half-rate improves voice quality compared to the present voice codec for half-rate channels, making the half-rate option a more attractive solution for increasing capacity.

Looking further ahead, better techniques for distributing traffic between GSM and WCDMA will be introduced until we can see a seamless GSM-WCDMA network, which will allow operators to use both technologies to their fullest, to maximize the end-user experience. It will also facilitate the introduction of new functionality in GSM. The introduction of adaptive antenna technology will yield even greater gains. Ericsson has tested adaptive antennas extensively to verify their performance. These tests show that adaptive antennas have the potential to more than double network capacity. In fact, it will be nearly doubled if adaptive antennas are installed at only 20-30% of the sites in a given area.

Conclusion

Radio network capacity solutions can be divided into three categories: cell capacity, network capacity, and channel capacity.

The one factor that has the greatest influence on cell capacity is frequency reuse. That is, cell capacity is determined by different frequency reuse methods and functions to enhance it. Two common methods are multiple reuse pattern and fractional load planning. A third frequency reuse method is non-uniform frequency planning.

To improve network capacity, operators can introduce micro cells, multiband operation (if additional spectrum is available), traffic management, and multilayered hierarchical cell structures.

Dynamic half-rate allocation technology enables operators to increase channel capacity for circuit-switched traffic during traffic peaks. Likewise, GPRS is a channel capacity solution for data communication—it makes optimum use of channels and maximizes capacity by allowing several users to share the same channels.

A recommended three-step approach to increasing capacity in the radio access network is as follows:

1. Activate frequency-hopping, employ tighter frequency reuse, and activate AMR.
2. If spectrum is available in a second band, deploy equipment in those frequencies. Add micro or indoor cells at hot-spots, and use dynamic half-rate allocation to reduce congestion during peak traffic.
3. Add more micro and indoor cells and increase the capacity in them.