Here are some system development hints that work whether you are adding coverage or capacity.

With an increasing number of users and greater interference, today's cellular systems operate in an electromagnetic jungle. Here are some technical suggestions in the area of traffic and drive test measurements. There are insights provided into some of the common causes of cellular degradation, as well as emerging applications for pedestrian-based propagation measurements.

**Coverage vs. Capacity**

The cellular system engineer is faced with a difficult task: Build the system for the highest customer satisfaction at the lowest cost. In rural cellular systems, or at the beginning of a system build-out, cells are installed to provide coverage in the service area. These cells are strategically placed to provide broad coverage throughout the market and are typically called coverage cells.

On the other hand, a maturing cellular system requires that new cell sites be added to support the increasing subscriber base. That is, instead of coverage being a factor, call blocking becomes a concern, and new cells must be added to increase the number of channels per area. When cells are added to provide more channels in specific geographic areas, they are called capacity cells. Figure 1 illustrates typical coverage and capacity cells.

There is a tension between coverage cells and capacity cells. Coverage cells are vital for capturing customers but generally require tall base station antennas. The tall antennas provide a large propagation footprint, which introduces interference to neighboring co-channel and adjacent cells. Thus, using large coverage cells actually reduces the practical capacity of the system due to interference. As the cellular system grows, the cell coverage must be shrunk to accommodate the additional cells needed for capacity.

Capacity cells, on the other hand, are pinpointed at “hot spots” where customer demand is known to be great (such as along a major bridge or freeway) and often require highly directional antennas and low transmission powers in order to localize the RF coverage. Managing the simultaneous frequency assignments and coverage zones of coverage and capacity cells is a difficult task in practice. As shown in Figure 1, however, a good measurement plan enables you to determine how your system is doing and what steps must be taken to fix the holes.

The mobile switching center (MSC) often contains diagnostic and monitoring software that allows the engineer to determine hourly, daily, weekly and monthly trends at each cell site in the system. The number of calls, handoffs, blocked calls or abruptly terminated calls per hour may often be read from the switch console. However, in practical situations, this data is difficult or impossible to extract, and without judicious field measurements,
does not provide a complete picture of how your cellular system needs to grow.

TECHNOLOGY VS. CELL SPLITTING

As an example of how the MSC alone cannot help determine the proper build-out strategy in a practical system, consider the case of a large urban cellular system that is adding customers at a rate of more than 50% per year. This growth rate will tax even the most conservative cellular system design, and the operator is forced to determine a strategy to handle more capacity.

One alternative is to adopt a cell-splitting strategy, which relies on microcells, cellular extenders or sectorized base stations. Changing out AMPS cellular equipment for N-AMPS or digital equipment is another alternative.

The proper choice depends on several factors, which include cost, time required for installation and frequency engineering, the current installed customer base and marketing strategy of dual-mode phones, the choices that your competitor made, and the current interference and capacity situation in your system.

In practice, each cell site is different, and what works at one site may not work at another. Although the MSC provides trends and statistics, only field measurements can be used to determine the particular co-channel interference levels on the forward and reverse channels in the vicinity of a cell site. Particularly with directional antennas, the coverage on both the forward and reverse direction must be thoroughly understood before a growth decision can be made. Fortunately, the capability of some measurement equipment makes gathering the data for growth decisions amazingly easy.

There is test equipment that scans the signal levels rapidly of all forward and reverse channels of competing systems and has complete decoding and SAT detection, making co-channel and adjacent channel measurements automatic in the field. You also can access statistics modes to determine the traffic intensity, signal levels and call statistics on several A and B band control channels at one time, allowing direct traffic comparisons between neighboring cells and the competition.

This traffic comparison not only includes typical measurements such as channel assignments, directed retries and paging mobiles, but also it includes the number of AMPS, N-AMPS and digital call requests; the number of registrations; and even the traffic along each sector of a base station. This type of data is extremely difficult to synthesize at the switch, yet is vital for determining proper growth decisions, antenna pattern placements and finding out what your competition is doing to eat into your own growth plans.

By carrying out an RF monitoring campaign that searches for interference (by scanning all active channels and their neighbors on the forward and reverse side) as well as capacity (by gathering traffic statistics on all nearby base stations on the forward and reverse channel), you are now armed with the data necessary to determine an appropriate engineering plan for the cell of interest.

FINDING NEW CELL SITES

Before investing the time and capital needed to grow your system, the "hot spots" should be well-understood. Again, the MSC is good at providing general trends and is an excellent starting point, but it is ultimately field measurements.
that allow you to pick the best site. Consider this practical example:

In a major city, the rush hour can be predicted fairly well by the MSC data, giving the engineering staff a rough idea of where new capacity cells must be added. However, the actual location of the new cell is an important decision that should always involve field measurements, as well as the actual type of antenna planned for the new site. Depending on traffic flow, traffic patterns and local landmarks, a few hundred feet may mean the difference between reaching 500 vehicles or 5,000 vehicles per hour, and a directional antenna may make the difference between marginal received signal and strong capture of the users in the desired hot spot.

Certainly, the real estate office finds the potential sites in an area, but these potential sites should also be selected by gathering statistics on the reverse control channels of the strongest few control channels in the vicinity. This is because the reverse control channel information offers you the best measure of the traffic activity, as well as the signal strengths of potential customers who will be using the new site. Because of the law of reciprocity in radio propagation, you can be sure that the prospective sites with the greatest level of traffic and strongest signals on the reverse channel will produce the greatest revenues. If you do not pick the best site for capacity, you will be losing revenue every day the cell is in operation.

One node available on some test equipment such as the Cellscope Pro, manufactured by Grayson Electronics, Forest, VA, has been designed specifically for reverse channel site analysis and keeps a running average of the reverse channel radio signal strength indications (RSSI) of all mobiles who originate and receive calls, or who autonomously register. A bar graph displays to allow you to point a directional antenna in the exact direction of maximum received signal strength.

While logging RSSI, you can keep a running average as well as track the smallest and largest RSSI value as a means of determining the statistical spread. You can determine the averaging interval, and it may range from a minute to several hours. This enables you to carry out reliable surveys for prospective capacity sites easily and automatically.

You also can scan to build a statistical measurement using an arbitrary number of control channels during the site survey. By using field measurement equipment to make surveys of reverse channel traffic and signal strength, you may make comparisons of prospective sites, and you can select the best site (in terms of revenue generation) without any guesswork.

**DRIVE TESTING**

Co-channel or adjacent channel interference is a problem in large urban systems with many co-channel base stations, whereas coverage “holes” are a common problem in small rural systems, particularly those with hilly terrain. These system maladies may be quickly diagnosed from proper field measurements.

**Interference drive testing:** Consider the problem of adjacent or co-channel interference (C/I). For the forward C/I case, the forward channel of a nearby base station interferes with the forward channel of the desired cell. Because the voice channels always use a smaller reuse pattern than the control channels (for AMPS, the voice channels use seven cell reuse, but the control channels use 21 cell reuse), it is only the voice channels that experience significant C/I. In a properly designed system, each neighboring co-channel cell uses a different SAT than its neighboring cell, thereby enabling the interference to be differentiated from the desired signal by the SAT tone — an interfering signal will have the wrong SAT.

On the reverse channel, C/I results from an out-of-cell subscriber interfering with the in-cell subscriber. In this case, the base station would seek to identify the proper SAT (from the in-cell user) and would recognize the SAT from the out-of-cell user as interference. When the interfering signal corrupts the desired signal, the SAT becomes corrupted, and the phone call is dropped after a few seconds, leading to poor service and customer complaints.

To find the locations in your system that provide these dropped calls, it is necessary to carry out a drive test, where the driver places one or more calls in progress and simply drives throughout the system, attempting to determine interference levels. Drive tests require an automatic position tracking device, such as a GPS receiver or a dead-reckoning vehicle sensor, so that all data are logged automatically.

**Coverage drive testing:** When determining coverage holes, it is a simple matter to set a specific received signal strength threshold at the measurement receiver, and then drive a particular route to see if the signal dips below the threshold. Such instances are flagged by the measurement receiver, which also logs the current position so that trouble spots can be identified and engineered properly once the drive test is complete.

**Best server drive testing:** A third type of drive test determines the best server for a particular location. This test is useful for determining the channels in which a mobile would camp to for channel assignments or call requests. By repetitively scanning the control channels of your system and those of your competitor, you can quickly find out which signalling channel an “undecided mobile” will select and how strong the channel is.

**USING MAPS**

For interference, coverage and best server measurements, plotting the measured data on a map is extremely useful and makes RF system performance much easier to understand and track. Fortunately, most high-performance measurement equipment comes with customized...
mapping utilities that directly read in the measured field data. Beware of measurement system vendors who insist on keeping their log file formats proprietary — it only means that they do not want you using the measurements unless you also purchase their mapping tools, which are inevitably more expensive or not as flexible as you would like.

One exception to the rule is the capabilities offered by MapInfo, Troy, NY. MapInfo develops and distributes a wide range of software databases and mapping tools. Grayson Electronics uses MapInfo software as the core of its mapping design tools that support Cellscope Pro log files. Grayson uses a public log file standard and also allows other measurement vendor data to be imported into its mapping tools, thereby providing the customer with maximum utility and flexibility for any mapping or measurement operation. Grayson even resells the MapInfo database at cost to help customers obtain the maps they need, and it has a real-time mapping capability for drive testing.

Examples of emerging measurements that cellular carriers will need to make include:
- Building penetration between outdoor cells and indoor cellular-based systems.
- Small-scale fading statistics within a fraction of a wavelength within stairways.
- Propagation measurements between walls or rooms of a building.
- Pedestrian/sidewalk measurements with dead-reckoning capabilities.

These measurements will be required because the capacity per square kilometer will increase substantially over the next few years, and new base station and antenna configurations, such as picocells, leaky feeders, and "parasitic" cellular systems (which use cellular channels inside a building under the control of an in-building wireless PBX instead of an outdoor cell site) are sure to emerge.

Even with these sleeker, more modern distribution systems, the basic limitations — coverage and capacity — will remain. Cellular engineers will need versatile, lightweight, multichannel hand portable measurement systems to design the cellular systems of the future.

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