COST-EFFECTIVE OPTIMIZATION OF MOBILE COMMUNICATIONS FOR DEVELOPING ECONOMIES

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Abstract

Mobile communications has become an indispensable element of modern lifestyle. The 3rd and 4th generations focus on high data-rate multimedia services and a host of respective applications, mostly leisure oriented. At the other extreme, mobile communications is a most effective driving force in boosting the economy of developing communities. These two processes may share technology momentum and the economy of scale, but their substantial differences have to be recognized. The introduction of mobile wireless services to developing communities is challenged by the cost of infrastructure, operations and user terminals of the advanced networks, and the mixture of older generation systems to coexist with the new deployments. Affordability considerations and priority of services dominate innovative architectural and optimization solutions to the infrastructure, choice of applications and user terminals.

Wireless Access Optimization is the major challenge to every wireless communications system. The classical cellular architecture provides only rough guidelines, and propagation modeling and statistics, and network simulations, fall short of representing and optimizing the actual network performance. Cost-aware Wireless Access Optimization governs the radio coverage at the Base Stations and additional RF access points (repeaters) as required by the environment and traffic demands. Optimal performance is achieved by combining prediction models with dynamic measurements, and applying coverage and diversity means accordingly. The optimization of the new data-optimized systems – EV-DO and HSDPA does not follow the same pattern, and compromises have to be taken when mixed services operate on the same network.

These techniques and respective experience are reviewed. Major savings in infrastructure costs have been shown, both in rural and in congested areas. The developing economies may take the leading role in developing Wireless Access Optimization, due to their cost-awareness, fast development of networks, and the keen interest to enhance the domestic value of the systems and the service.

CELLULAR SCENE FOR DEVELOPING COMMUNITIES

Cellular penetration exceeds 100% penetration in most developed communities and is considered an indispensable element in the modern lifestyle. The voice-centric service is giving way to multitude data services – from messaging to internet and video. While the third generation, built to provide these services, is only now picking up speed in deployment worldwide, it is already being upgraded to high data rate services – HSDPA for UMTS and EV-DV for CDMA 2000, and challenged by wideband technology striving to become fully mobile.

The respective infrastructure is undergoing continuous upgrades and changes while trying to provide the new services at minimum cost. The differences in the air interface, user distribution and load dynamics – between these generations, leave the common infrastructure underutilized, awaiting new dynamic resource management.

While the ubiquitous wireless is overcastting the developed world, over 80% of the world population is still lacking the basic connectivity. There are multiple humanitarian reasons to justify the introduction of communications to this vast population. The driving impetus for the industrial world to invest in these projects, however, is that communications creates new markets. Communications boosts the domestic economy, increases its buying power and exposes the community to market offering. Wireless infrastructure is faster to deploy and less expensive. It so happens, then, that introduction of cellular services to developing communities takes place alongside with or ahead of introduction of other communications services.

New installations of cellular networks tend to be supplied from the last technology vintage – 2nd and 3rd generations, on top of older equipment and WLL previously installed. Affordability is the key challenge for these projects. The affordable cost of service is more than an order of magnitude lower than that accepted elsewhere, which reflects on the equipment, infrastructure and type of services. Surmounted on this is the need to cover extremely low density areas. The density of the rural community varies from densely clustered villages to extremely sparse population – challenging the cost of such a sparse and non uniform deployment.

Creative approach has to be adopted, capitalizing on utilization of domestic products and services in installation and operation of the networks, and optimizing the networks for the type of services needed by these communities: voice and SMS.

SALIENT FEATURES OF THE CDMA NETWORKS

The 3rd generation cellular standards, and part of the 2nd generation, are CDMA-based. There are salient features of CDMA that affect the cost and performance, to be considered at the planning and later optimization of the network. The uplink and the down link have different structures, and respond differently to network load. The frequency reuse throughout the network, using random codes as the subscriber filter, power control within each cell and soft handover (SHO) between them, automatically links the whole network, per channel(1.25 MHz or 5 MHz). The downlink is not automatically balanced with the uplink, however, and balancing is a part of the optimization process, and is sensitive to the cell environment, activity distribution, and the load in the adjacent cells. These differences are summarized in Table 1.

Table 1: Up and Down Links features in CDMA

	Up Link	Down link
Capacity limit	Other users' Interference	BTS Power
Coverage limit	User's power	BTS power
Power control	Controlled by aggregate interference to the BTS	Controlled by link budget and interference to the MS
Cell boundary	Shrinks when loaded	Expands when loaded

MINIMIZING COST AND OPTIMIZING THE USAGE OF THE RESOURCES

The controllable radio parameters that lend themselves to optimization:

- *Channel quality*. Reduction of fading by application of diversities increases the receiver sensitivity and reduces the required power resources, and the interference.
- *Path-loss*. The path-loss across a large cell exceeds 80 dB. "Radio holes" in shadowed areas add to the power drainage from the BTS, reduce the performance and the capacity. Power is the largest cost driver in the infrastructure. Properly distributing remote sectors and repeaters reduces the power required per subscriber substantially.
- *Link balancing*. Link imbalance induces extended SHO zone, pilot pollution, dropped calls and access attempts failure.
- *Load balancing*. Excess load from saturated cells can be shed to the neighbors by coverage control means.

DIVERSITY RECEPTION AND TRANSMISSION

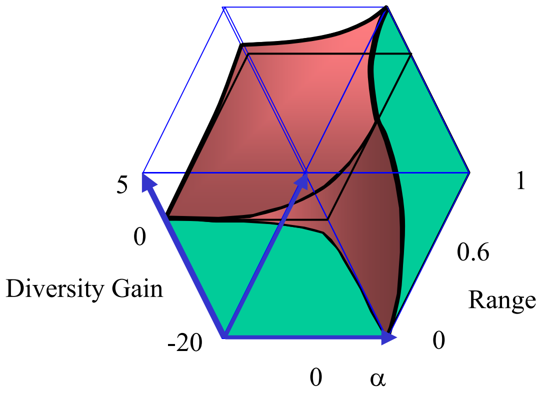
Effective diversity reduces the required Eb/Io at the receiver and thus increases the dynamic range of the link. Transmit power can be reduced, or range and capacity increased. Transmit diversity is not a standard feature in 2nd G, and not always applied in 3G. Add-on applications utilize RF delay (TDTD), creating artificial multipath, or phase sweep/ modulation (PSTD). The first adds both diversity and additional noise, and is effective toward the edge of the cell, supporting its extension. It degrades the high Eb/Io near the cell core and thus it limits the high-end data rate of EV-DO/ EV-DV and of HSDPA. The PSTD, on the other hand, creates artificial fading, at a rate that is recoverable by the interleaver decoder of the receiver, and its effect resembles selective diversity when the channel is fading in the first place, but it raises the required Eb/Io for more benign channels. This is clarified by relating to the down link equation

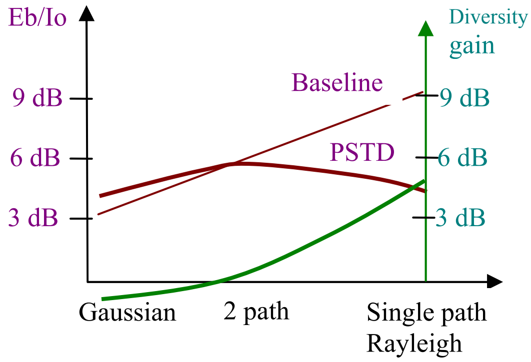
$$\frac{E_b}{I_0}(r_i) \propto \frac{g}{(1-\alpha)P_{BTS} + N(r_i)} \tag{1}$$

where α is the orthogonality factor, P_{BTS} – the BTS power, g – the diversity gain and N(r) is a noise term, that is negligible near the cell center and grows to dominance toward the cell edge. Recasting the equation into

$$g \propto \frac{E_b}{I_0}(r_i) \bullet ((1-\alpha)P_{BTS} + N(r_i)) \tag{2}$$

it becomes clear that the TDTD, where $\alpha \le 1/2$ by the introduction of the extra delayed signal, lowers the Eb/Io near the cell center and becomes effective toward the edge, while PSTD is most effective for high α near the cell center, and slow motion. These two methods are complementary in their application.





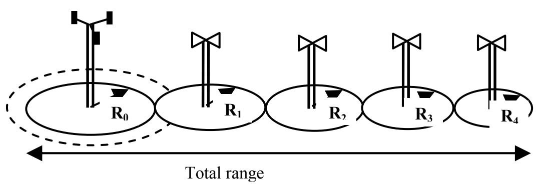
a: TDTD b: PSTD

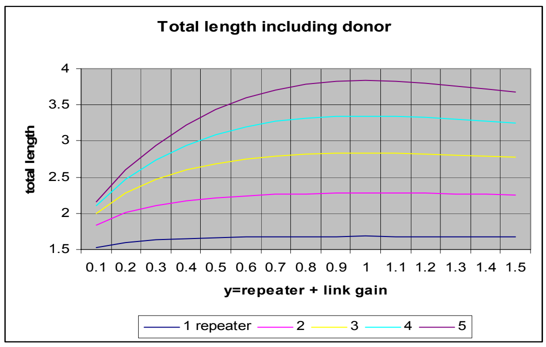
Fig.1: Diversity gain of TDTD and of PSTD

Space diversity relies on decorrelation of the receiving (or transmitting) antennas, and its effectiveness relates to the angle spread of the transmitted (received) signal by scatterers. The gain is degraded in rural area and near line of sight situations, where the large spacing required between the antennas become impractical. Polarization matching, on the other hand, is effective in such situations. The diversity combining circuit of the orthogonally polarized antennas serves as polarization matching to the user antenna polarization, retrieving high "polarization holes" and gaining an average of 3 dB for a user population with uniformly distributed polarization. The same system serves as a benign polarization diversity scheme in dense urban environment. Space and polarization diversity thus have complementary applications.

REPEATERS AND DISTRIBUTED ACCESS

Repeaters are low-cost means for distributing the radio access, which serve for coverage extension. A repeater in a CDMA network is an RF access point that interfaces to a Base Station (BTS) at the RF (or IF) level and shares the BTS resources with the BTS antennas and/or other repeaters. As such the users served by the repeater share the BTS resources with those served by the BTS and are controlled by the same BTS rules, including power control and Soft Hand-Over. These introduce inter-relations between repeater parameters and impose limiting factors. The overall gain of the repeater in the up link (the amplifier gain times the loss in the link to the donor cell) controls the repeater coverage, but at the same time – the level of repeater self noise that is injected to the donor BTS receiver, and thus limits the donor cell coverage. The down link gain and power is tuned to balance the link. A different trade-off is applied in application of the repeater for extending coverage, covering "radio holes", and "hot spots" – and in cascading repeaters for covering long roads or a chain of villages. The latter is exemplified in fig. 2, showing that one BTS and 4 repeaters can replace 4 BTSs when covering a corridor is considered.





a: Cascaded repeater chain b: Coverage length for cascaded repeater chain

Fig. 2: Cascaded repeater chain for coverage of roads and villages' corridor

LINK BALANCING

The up and down links are not necessarily balanced. Imbalance results in a loss of coverage, capacity and performance. Balance between the down and the up link, at the cell boundary, means the adjustment of the links' parameters so as to match the Soft Hand Over conditions for both links for each user. A balance can be achieved by adjusting the pilot power such that the Ec/Io of the pilots of adjacent cells match at the same location where the up links to both cells balance. Control of the tilt of the BTS antenna is an alternative mean, less intrusive to the BTS. Such an adjustment depends on load parameters of both cells for both links. Balancing conditions are plotted in Fig. 4 for a range of load in the cell and ratio between the other cells' to self load. Dynamic balancing, reacting to changes in network load, requires online probing and control of the network parameters, and online control of the pilot power and antenna tilt.

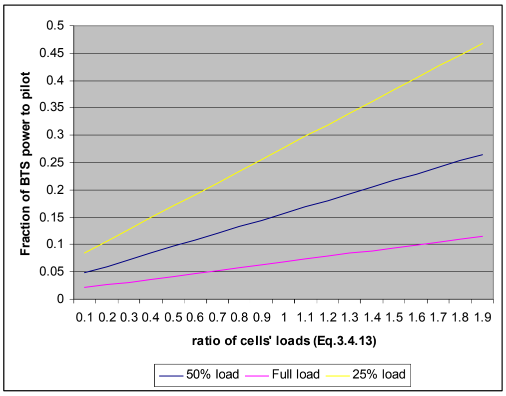


Fig.3: Pilot power setting for balancing a large cell

LOAD BALANCING

Load balancing between adjacent cells is treated by coverage control between cells and sectors, that shifts excess subscribers from the loaded cell. This is served by proper choice of antennas, their orientation and tilt, a process that requires manual maintenance. Remote Electrically Tilt (RET) antennas enable dynamic load balancing. Their application becomes cost-effective even in low labor cost markets when frequent optimization is required.
Repeaters that "loan" capacity from a donor cell into a "hot spot" in another loaded cell serve the same purpose for non uniform density situations. These can be gain-controlled to match the need. These repeaters have to be linked by fiber or out-of band RF link.

SUMMARY AND CONCLUSIONS

Low economy communities have been recognized as a potentially huge commodity market, which brings together the interests of their governments and those of the wealthy world industries to provide them with enabling communications. These systems are intended for growth and for service diversity, along with the growth of buying power of the community, and consist of latest vintage of cellular. The constraint of affordability imposes a unique challenge. Conservative, equipment rich design that typifies installations in developed areas, has to give way to creative solutions, based on profound understanding of the radio access interaction. The CDMA network is sensitive to the local channel environment and distribution of activity. It lends itself to high capacity and high efficiency only though careful optimization, sensitive to the locality of the interactions. The dynamics involved in periodic shifts of load, in network continuous growth and development of services, justifies the development of dynamic control to the network even for the low labor cost communities. An intensive effort toward reduction of costs in capital and operations, while preserving the flexibility for growth, is a bare necessity for the developing countries. The development of centers of excellence for innovative affordable cellular networks may prove to be the best investment for both the governments and the operators in these countries.