

## TELCOM 2720 Cellular Radio and PCS

### *Fundamentals of Wireless Communication Systems*

As noted in the first lecture there are three basic ways in which wireless communication systems are fundamentally different from their wired counterparts namely: 1) the wireless communications channel (i.e., poor quality, bandwidth limitations, security etc..) 2) user mobility and 3) power limitations. Each of these differences has a significant impact on the system and the architecture used.

The poor quality of the wireless communications channel is due to a variety of adverse transmission and propagation effects including: propagation path loss, atmospheric effects, multipath fading, shadowing, Rayleigh fading from movement, cochannel interference, and adjacent channel interference. The end result of these channel impairments is that the wireless channel quality depends on space and time. A variety of special techniques will be employed to improve the channel quality such as, power adjustment, frequency separation, error control coding, interleaving, and equalization.

The frequency bands, bandwidth and power levels for wireless systems are heavily regulated by governments. In fact the bandwidth available to any one network/service is limited and the license to operate in the given bandwidth at a specific location is very expensive. Thus the communication system must efficiently use the given spectrum. This results in careful frequency planning and use of the cellular concept to extend the system capacity, along with the use of multiple access techniques to control use within a cell.

Most wireless systems support some form of "user mobility". This means that the network must track the user's location, have the user's service profile follow them and possibly do handoffs from one transmitter/receiver to another. Tracking the user implies the need for user registration and paging of the user. Also, note that mobility further worsens the communication channel.

In order to reduce interference and extend battery life constant power level adjustments are made.

The Goodman textbook similarly lists these differences slightly regrouped into the categories of ether, energy and mobility. These differences result in technical hurdles that must be overcome to implement a wireless system. We now look at some of the basic techniques used in part to overcome these hurdles. The wireless systems we will study (e.g., cellular phone, wirelessLAN, WLL, LEO satellites) will employ some combination of these techniques in the system implementations based on design/cost/performance tradeoffs.

### *Radio Basics*

As the name implies, wireless communication systems include a wireless link - normally as the last link from the network to the user. Communications over the wireless link for the systems we will study takes place via radio waves over the air. A typical radio communication systems is shown on page 1 of the handout. Following the transmission path from sender to receiver shown in the figure. The information source signal (audio, data or video) is first passed through various signal processing functions which appropriately filter and code the signal (e.g., bandlimiting signal, A/D conversion, error control coding, vocoding, etc.). Next the signal is modulated to the carrier frequency - resulting in the information signal being shifted in the frequency domain to the appropriate radio channel. The amplifier/antenna combination transmits the signal obeying specifications for bandwidth and power limits. After the signal propagates through the air to the receiver the receiver must select the desired signal, filter/remove noise, demodulate, decode and amplify the information signal. For two way communication each end of the wireless link must have both a transmitter section and a receiver section. This combination of a transmitter and receiver is called a *transceiver*. As we will see there are a variety of design choices in each of the components in the transceiver. For example, the modulation

can be AM, FM or PM if the information is kept in analog form; in that case of digital information the modulation can be ASK, FSK, PSK or the many variants like DQPSK, QAM etc. The bottom figure on the second page of the handout shows the different types of modulation techniques. In wireless systems AM and ASK are generally not used due to poor noise immunity.

The operating frequency band of the wireless system has an effect on the channel characteristics, range and power requirements of the system. In general the higher the frequency, the more complicated and expensive the equipment and the signal strength decays faster with increasing distance from the transmitter. The wireless systems we are studying mainly operate in the radio band of the frequency spectrum which extends from 3 KHz to 300 GHz. Remember the frequency  $f$  in Hertz is how many cycles of a sinusoid there are per second and the wavelength  $\lambda$  in meters is  $\lambda = c/f$  where  $c$  is the speed of light ( $3 \times 10^8 m/s$ ). The figure on page 3 of the handout shows the radio spectrum and corresponding wavelength. In the U.S. the FCC regulates the radio spectrum and assigns frequency bands for various applications. Within the radio spectrum the U.S. frequency bands for some of the wireless systems we will study are

**cellular phone:** 824-894 MHz or PCS band 1.8 - 2 GHz

**wireless LANs:** 902-928 MHz, 2.4-2.485 GHz, 5.7-5.825 GHz, or Infrared.3 - 3 THz

**LEO satellites:** L band (up 1535-1542.5 MHz, down 1635-1644 MHz), C band (up 5.9-6.4 GHz, down 3.7-4.2 GHz), Ku (up 14-14.5 GHz, down 11.7-12.2 GHz) and Ka band (up 27-31 GHz, down 17-20GHz)

**wireless local loop, LMDS:** paging and cellular/PCS bands; Block A: 27,500 - 28,350 MHz, 29,100-29,250 MHz and 31,075-31,225 MHz; Block B: 31,000-31,075 MHz and 31,225-31,300 MHz.

The exact frequency band used by a system depends in part what band is licensed for that use in the country of interest. For example the original analog cellular system in the U.S.

was in the bands 824-894 MHz whereas in Europe it was primarily in 890-960 MHz and in Japan in 860-925 MHz. Note that a system operating in a particular band normally only gets a portion of the bandwidth allocated. For example the 824-894 MHz band for cellular phone service in the U.S. is divided evenly among two service providers.

### Wireless Propagation Models and Path Loss

Unlike wired channels where signal strength is relatively stationary and predictable, in wireless channels the signal strength varies with time and location. In order to predict signal strength for cell planning and deployment various analytical models have been proposed and are still being developed. These models are propagation-loss models which focus on power loss over the communications path from transmitter to receiver. The models can be categorized into large scale (LS) models and small scale (SS) models. The former predict **mean** signal strength and transmitter-receiver separation distance  $d$ . The latter models predict random fluctuations over a short distance or short time duration around a fixed transmitter-receiver separation distance  $d$ . In both LS and SS cases one focuses on the path loss  $PL$  which represents the signal attenuation as a positive quantity measured in decibels. The path loss is defined as the difference between the effective transmitted power and the received power and may or may not include the effect of antenna gains. Thus the path loss in dB is defined as:

$$PathLoss = PL(dB) = 10 \log \left[ \frac{P_t}{P_r} \right]$$

where  $P_t$  is the power of the transmitter and  $P_r$  is the power of the received signal. Note that  $P_t$  and  $P_r$  are normally expressed in watts (W), but due to the large range the signals may take, they may be expressed in decibel watts (dBW) or decibel milliwatts (dBm). For example for  $P_r$

$$P_r(dBW) = 10 \log \left[ \frac{P_r(W)}{1(W)} \right]$$

$$P_r(dBm) = 10\log\left[\frac{P_r(W)}{.001(W)}\right]$$

Note that the three basic concepts that apply to determining path loss from LS models are: 1) Free space loss, 2) Ground reflections and 3) Diffraction. In cellular systems the path loss at a particular location will be a combination of these and other effects. We will briefly look at simple models for each case.

### Free space loss

Free space loss models a best case scenario where the transmitter and receiver have a clear unobstructed *line of sight* path between them and both antennae are surrounded by empty space with no other object close enough to interact. In this situation the only propagation effect is the natural spreading out of the radiowave at greater and greater distances from the transmitter (think of an expanding sphere as shown in the top figure on page 4 of the handout). From physics one can show for this case that

$$P_r = P_t G_t G_r \frac{\lambda^2}{(4\pi d)^2} \quad (1)$$

where  $G_t$  is the gain of the transmitter antenna,  $G_r$  is the gain of the receiver antenna,  $\lambda$  is the wavelength in meters, with  $\lambda = \frac{c}{f_c}$ , where  $f_c$  is the carrier frequency and  $c$  is the speed of light which is  $c = 3 \times 10^8 m/s$ . Note if one knows the received power at some distance  $d_o$  from the transmitter then from (1) it can be shown that for a distance  $d$  from the transmitter the received power is just

$$P_r(d)(dBm) = P_r(d_o) + 20\log\left[\frac{d_o}{d}\right]$$

Example 1: A PCS cell site produces 50 W of power and the system uses unity gain antennae at transmitter and receiver. What is best case  $P_r$ , in dBm at 100 m and

10km.

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} = \frac{(50)(1)(1)\left(\frac{3 \times 10^8}{900 \times 10^6}\right)^2}{(4\pi)^2 (100)^2} = 3.5 \times 10^{-6}$$

$$P_r(dBm) = 10 \log\left[\frac{P_r}{0.001}\right] = -24.5dBm$$

$$P_r(10km) = P_r(100) + 20 \log\left[\frac{100}{10,000}\right] = -24.5dBm - 40dB = -64.5dBm$$

From (1) we have the path loss for free space  $PL_{fs}$  in dB as

$$PL_{fs} = 10 \log \frac{P_t}{P_r} = 10 \log \left[ \frac{G_t G_r \lambda^2}{(4\pi d)^2} \right] \quad (2)$$

From this formula one can see that in the best case scenario the signal decays 20 dB per decade increase in  $d$ . Also, one can see that the path loss increases with  $f$  at a rate of 20 dB per decade increase in  $f$ . For the case of  $G_r = G_t = 1$  one can show from (2) that

$$PL_{fs} = 32.44 + 20 \log(f) + 20 \log(d) \quad (3)$$

where  $f$  is in MHz and  $d$  is in km

Example 2. Compare the free space path loss at 1km and 5 km of two signals one in the lower cellular band at 880 MHz and the other in the PCS band at 1960 MHz. Assume unity gain antennae are used. From (3) one gets

Distance	880 MHz	1960MHz
1km	91.29	98.25
5km	105.27	112.23

Thus the PCS band has at least a 7dB greater path loss in the free space case.

## Ground Reflection

Ground reflection occurs when a propagating radiowave strikes the earth surface. Depending on the angle of incidence and the reflection coefficient of the surface, all or part of the radio wave is reflected back into the air. This reflected wave will have a phase shift due to the longer distance traveled and can partially cancel the direct line of sight signal. The case of interest for cellular systems is shown in the bottom figure on page four of the handout. Let  $h_t$  be the base station transmitter height in meters,  $h_r$  be the height of the mobile receiver in meters and  $R_C$  be the reflection coefficient. From the geometry of the diagram one can show the phase difference  $\Delta$  between the line of sight signal and the reflected signal is given by

$$\Delta = \frac{2\pi}{\lambda} \left( \sqrt{d^2 + (h_t + h_r)^2} - \sqrt{d^2 + (h_t - h_r)^2} \right)$$

Notice that the larger the distance from the transmitter  $d$  the greater the phase shift. The power at the receiver is just the phasor sum of the two received signals and is given by

$$P_r = P_t G_t G_r \left( \frac{\lambda}{4\pi d} |1 + R_C e^{j\Delta}| \right)^2$$

Assuming the worse case of all the signal being reflected then  $R_C = -1$  and for distances of  $d \gg 4h_r h_t / \lambda$  one can approximate the received power by.

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4} \quad (4)$$

From (4) notice that as the receiver moves larger distances from the transmitter the power falls off with distance raised to the fourth power. Converting (4) into the reflection path loss  $PL_r$  yields

$$PL_r = 40 \log(d) - (10 \log(G_t) + 10 \log(G_r) + 20 \log(h_t) + 20 \log(h_r)) \quad (5)$$

Notice that the signal decays 40 dB per decade increase in km independent of  $f$ .

## Diffraction

Diffraction occurs when a large object (as compared to transmitter and receiver heights) blocks (i.e., obstructs) a line of sight path between the transmitter and receiver. The figure on page five of the handout shows a simple diffraction scenario. In the figure  $h_m$  is the height of the obstruction,  $d_t$  is the distance from the transmitter to the obstacle and  $d_r$  is the distance between the receiver and the obstacle. Diffraction results in the received signal traveling a longer distance and being attenuated by the obstacle. The extra path loss due to the obstacle can be related to the diffraction parameter  $v$  which is defined by

$$v = h_m \sqrt{\frac{2}{\lambda} \left( \frac{1}{d_t} + \frac{1}{d_r} \right)} \quad (6)$$

The path loss from diffraction  $PL_d$  is given by

$$PL_d = \begin{cases} 6 + 9v - 1.27v^2 & 0 < v < 2.4 \\ 13 + 20 \log v & v \geq 2.4 \end{cases} \quad (7)$$

The path loss from diffraction should be added to the other path losses that are appropriate to the situation, such as free space loss.

**Example 3:** A base station operating in the cellular band produces 10 W of power, uses an antenna with gain 10 at the transmitter and antenna at the receiver with gain 2. A mobile at a distance of 5 km from the base station is receiving a call from the base station on the 900 MHz frequency. There is a 395m hill between the base station and the mobile, with the base station 3 km from the hill and the mobile 2 km from the hill. Determine the power received at the mobile.

The power received at the mobile will be given by the power received under free space conditions minus the diffraction path loss. Estimating the free space received power  $G_t = 10$ ,  $G_r = 2$ ,  $f = 900 \times 10^6$  and  $d = 5000$ . Thus from (1) we get

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} = \frac{(10)(10)(2) \left( \frac{3 \times 10^8}{900 \times 10^6} \right)^2}{(4\pi)^2 (5000)^2} = 5.64 \times 10^{-9}$$



$$P_r(dBm) = 10 \log\left[\frac{P_r}{0.001}\right] = -52.48 dBm$$

From (6) above we get

$$v = 395 \sqrt{\frac{2}{1/3} \left( \frac{1}{3000} + \frac{1}{2000} \right)} = 27.93$$

which results from (7) in a  $PL_d = 41.92$ , thus the actual power received is  $P_r(dBm) = -52.48 - 41.92 = -94.401 dBm$

### Measurement Based Models

While it would be preferable to utilize the analytical models discussed above in determining radio coverage and signal strength, unfortunately these models are not very accurate. The type of models that have become popular in practice are empirical based models which involve curve fitting to measurement data collected from test drives in typical environments. This curve fitting is illustrated in bottom figure on page six of the handout.

The two of the most popular measurement based models for determining path loss are given on page six of the handout and are the Okumura-Hata model and COST-231-Hata model which are given by equations (8) and (9) below. These two models estimate the path loss in dB. The Okumura-Hata model is tailored to the cellular band around 800 MHz, whereas the Cost-231-Hata model is specified for the PCS band around 1900 MHz.

*Okumura-Hata*

$$PL_{oh} = 69.55 + 26.16 \log(f) - 13.82 \log(h) + [44.9 - 6.55 \log(h)] \times \log(d) + C \quad (8)$$

*Cost-231-Hata*

$$PL_{c2h} = 46.3 + 33.9 \log(f) - 13.82 \log(h) + [44.9 - 6.55 \log(h)] \times \log(d) + C \quad (9)$$

where  $f$  is the frequency in Mhz,  $d$  the transmitter-receiver separation in km,  $h$  is the effective height of transmitter antenna (i.e., the difference between height of transmitter

antenna and height of receiver antenna) and C is an environmental correction factor in dB as shown below.

Environment	Okumura-Hata	Cost-231-Hata
Dense Urban	-2	0
Urban	-5	-5
Suburban	-10	-10
Rural	-26	-17

The environmental factor roughly adjusts for the differences in environment due to obstructions, ground reflections, etc. In the figure on the middle of page six of the handout, typical results from the two models are given in terms of calculating the cell radius, for an omnidirectional antenna at the base station and a receiver signal strength requirement of -92 dBm. The calculations are similar to the example below. Notice from the figure that all things being equal a PCS band base station will have a smaller coverage area than a cellular band base station due to the propagation effects at higher frequency.

*Example 4.* You are designing an AMPS cellular system for Greater Pittsburgh for a carrier with a set of 416 radio channels in the A side frequency band (824-835, 845-846.5 MHz for reverse link , 869-880, 890-891.5 MHz for forward link). The base stations to be deployed produce 40W of power and use 10dB gain omnidirectional antennas. The mobile handsets require a signal level of  $-90dBm$  and use antennas that produce a 3dB gain. The base stations will be located such that the average effective height difference between the cell site antenna and the user is 100 m. Using the Okumura-Hata propagation model determine the maximum radius for a cell in an urban environment.

The worst case propagation is at the maximum frequency in the band of 891.5 MHz. Determining the path loss from (8) we get

$$PL_{oh} = 69.55 + 26.16\log(891.5) - 13.82\log(100) + [44.9 - 6.55\log(100)] \times \log(d) + 5$$

$$= 114.0852 + 31.8 \log(d)$$

The received power at the mobile  $P_r$  must be greater than -90 dBm and is given by

$$P_r = P_t + G_t + G_r - PL_{oh}$$

and results in

$$-90 \leq 10 \log\left(\frac{40}{.001}\right) + 10 + 3 - (114.0852 + 31.8 \log(d))$$

$$-34.935 \leq -31.8 \log(d)$$

$$12.549 \geq d$$

Thus the maximum cell size is about 12.5 km.

As noted above large scale propagation models predict the mean signal strength at a transmitter - receiver separation  $d$ . Whereas, small scale models predict the signal strength for small distances (a few wavelengths or tens of wavelengths) around  $d$ . Small scale models focus on including the effects of the local environment and movement. We look at two particular models below

### Shadowing

The local mean received power  $P_r(d)$  at a transmitter-receiver separation  $d$  is determined in part by the local environment of buildings, trees, cars, etc. as shown in the top figure on page 7 of the handout. One approach to modeling these shadowing effects is a statistical model where a random component is added to the mean received power predicted by a LS model. This results in

$$P_r(d) = P_t - PL(d) + X_\sigma \tag{10}$$

where  $P_t$  is the transmitter power,  $PL(d)$  is the path loss - which is determined from one of the LS models presented previously, and  $X_\sigma$  is the shadowing loss with all terms

being in dB. Measurement studies have shown that in cellular systems the shadowing has a lognormal distribution in terms of variations in the signal strength, which results in a Normal distribution with mean zero and standard deviation  $\sigma$  for the term  $X_\sigma$  in dB. The value of  $\sigma$  at a particular location is usually determined by measurements, with typical values being: rural 3 dB, suburban 6 dB, urban, 8 dB, dense urban 10 dB. Since  $X_\sigma$  has a normal distribution and the other terms on the right hand sided of (10) are deterministic the overall received power  $P_r(d)$  has a normal distribution with mean equal to  $P_t - PL(d)$  and standard deviation  $\sigma$ . This fact is often used to determine the % or probability of radio coverage at the edge of a cell. This amounts to determining what the probability of the received signal power being above a given threshold  $T$  is at distance  $d$ , which is given by  $P\{P_r(d) \geq T\}$ . The threshold value  $T$  is usually the minimum signal strength requirements of the mobile terminals. Since  $P_r(d)$  has a normal distribution with mean of  $P_t - PL(d)$  the probability of being above a certain level can be found from the standard normal (0,1) random variable  $Z$ .

$$P\{P_r(d) \geq T\} = P\left\{Z \geq \frac{T - (P_t - PL(d))}{\sigma}\right\} \quad (11)$$

In practice one is more interested in determining a path loss requirement which must be considered to ensure coverage at a threshold value  $T$  for a given distance  $d$ , this additional path loss requirement is termed the shadow margin ( $SM$ ). From (10) a particular quantile value such as .9 or .95 can be found, in fact these values depend only on  $\sigma$  and are determined from the standard normal random variable as .9 quantile  $\longrightarrow SM = 1.282\sigma dB$  and .95 quantile  $\longrightarrow SM = 1.645\sigma dB$ .

*Example 5.* For the system of Example 4, measurements show that lognormal shadowing occurs in each cell with a standard deviation of 8 dB. If we require that 90% coverage area in each cell meet the -90 dBm signal level what must the mean received

signal level (i.e., what is the shadow margin required) ? Using the SM results resize the maximum cell radius for using the Okumura - Hata propagation model.

From above for 90% coverage we want the .9 quantile level of the normal distribution which results in a  $SM = 1.282\sigma = 10.26dB$ . Adding in the SM requirements results in

$$P_r = P_t + G_T + G_r - PL_{oh} - SM$$

$$-90 \leq 10\log\left(\frac{40}{.001}\right) + 10 + 3 - (114.0852 + 31.8\log(d)) - 10.24$$

$$-24.69 \leq -31.8\log(d)$$

$$5.98 \geq d$$

Thus the maximum cell size is about 6 km.

## Rayleigh Fading

In addition to the propagation effects studied above a very important effect is fast fading that occurs due to the combination of a multipath propagation environment and user mobility. A typical fast fading signal is shown on the bottom figure of page 8 of the handout. As illustrated in the figure as a user moves through a location, fast fades occur resulting in signal values 10-30 dB below the mean value. These fades occur at every half wavelength apart  $\lambda/2 \approx 20cm$  in cellular band or  $\approx 7.5cm$  in PCS band. This fast fading happens at all distances of transmitter-receiver separation when the mobile is in motion and is due to the phase change or Doppler shift in the received signal. This Doppler shift is illustrated in the top figure on page 8 of the handout. Where a vehicle traveling at velocity  $v$  will travel distance  $d$  during the interval  $\Delta t$  of receiving the signal from the source  $S$ . This results in a phase change of  $\Delta\theta = 2\pi\Delta l/\lambda = (2\pi v\Delta t\cos\theta)/\lambda$  which results in a Doppler shift or frequency change of  $f_d = \frac{vf_c}{c}\cos\theta$ . The maximum frequency shift

$f_D$  will occur when traveling directly toward/away from the transmitter and is given by

$$f_D = \frac{v f_c}{c}.$$

In terms of studying the effect of fast fading on the system one would like to know the depth of fading (i.e., how many dB down from the mean value) and how often significant fades occur. This can be studied for two different cases. When a strong dominant line of sight signal is present the light fading that occurs has been model by a Ricean probability distribution, for the case when no line of sight exist the fading has been modeled by a Rayleigh distribution. The Rayleigh case is the most problematic and the Rayleigh probability density function is shown in the middle figure of page 8 of the handout and below where  $\sigma$  is the rms value of the signal before envelope detection.

$$f(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right) \quad 0 \leq r$$

From this density one can show that the number of fades of depth  $R$  occur at rate

$$N_R = \sqrt{2\pi} f_D \rho e^{-\rho^2} \quad (12)$$

where  $\rho = R/R_{rms}$  is the normalized fade depth. The mean fade duration  $\tau$  for a specified level  $R$  is given by

$$\tau = \frac{e^{\rho^2} - 1}{\rho f_D \sqrt{2\pi}} \quad (13)$$

The depth of fading and the duration is often used to specify the error control coding used in digital system along with the symbol duration.

*Example 6* Consider a vehicle traveling at 30 meters/sec that is making a cellular phone call at 900 MHz. Assuming the rms value of the recieved signal stays relatively constant over the period of interest and there is no line of sight between the vehicle and the cell site (thus Rayleigh fading is appropriate model).

(a) Determine the average fade duration for a signal level 10 dB below the rms value

$$(10dB\ fade \Rightarrow \rho = .316)$$

$$f_D = v * f_c / c = 90\text{ Hz} \text{ which from (13) results in } \tau = 1.5 \text{ msec}$$

(b) How many 10 dB fades would occur during a 10 second interval?

From (12)  $N_R = 64.5$  fades per sec Total in 10 sec = 645 fades

(c) Repeat (a) and (b) for frequency 1900 MHz (the PCS cellular band)

$$f_D = 190 \text{ Hz}, \tau = 0.7 \text{ msec } N_R = 136.2 \text{ fades per sec. Total in 10 sec} = 1362 \text{ fades. Notice that the PCS band has more fades of a longer duration.}$$

### **Prediction/Planning Tools**

Experts often make the analogy between radio propagation prediction and weather forecasting in that they have about the same accuracy. This analogy also holds in being location dependent since just as there are places where it is possible to accurately predict the weather (e.g., southern California) and places where it is difficult (Pittsburgh), the same holds true for predicting radio propagation. In practice, companies use a variety of computer aided design (CAD) tools for prediction and planning. On the class web page links are provided to typical planning tools (both LAN and cellular/PCS). The basic format of CAD planning tools is shown in the bottom figure on page 9 of the handout. In the cellular/PCS format the tools incorporate a terrain/geographic database of the area along with a traffic density overlay in terms of population and vehicle traffic. The output of these tools is an output map (in various colors) which shows radio coverage at specific levels (or probabilities) and interference values. The top two figures on the page 6 of the handout show screen dumps from two typical cellular CAD tools. In general these tools use a variety of prediction models similar to the ones discussed above (i.e., Free Space, Okumura-Hata, etc.). One approach that is often used is ray tracing - where a series of rays are drawn from the base-station antenna and from the geographic information the

appropriate propagation model is used to predict the signal strength. Note some models allow for the determination of penetration into buildings and cars as well as uniform coverage. Also, many of the CAD tools allow for the incorporation of measurement data to improve the accuracy of the models. Furthermore, most cellular tools allow for link budget computations to ensure signal strength at various distances. In general before deploying a cell service providers usually put up a test base station and take extensive measurements to actually determine the coverage and interference. In fact measurement data is for the most continually gathered from operational systems in order to tune the system performance.