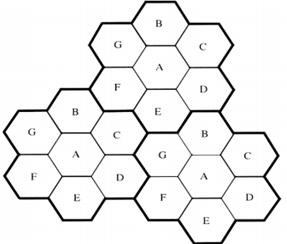
WIRELESS COMMUNICATIONS

ASSIGNMENT – II

Mandeep Sarangal

251000108

1. **Consider a cellular service provider in London, Ontario is allocated the spectrum bandwidth for 210 channels (210\*50Khz = 10.5Mhz), and its coverage area is divided into 21 cells, as show in Figure 1.**



Cellular communication system for Question 1

**(a) Determine the maximum of active users can be supported at same time when there is NO frequency reuse.**

Each cell can support 10 users, if the distribution of the active users is even.

Therefore, active users supported = 21 x 10 = 210

**(b) Determine the system capacity with cluster size of 7 and 3, respectively.**

For cluster size of 7: All cells are grouped into cluster of 7 cells and each cluster employs all of the frequencies. This means that the capacity is increased by a factor of 3.

Therefore, Capacity = 210 x 3 = 630 channels

For cluster size of 3: All cells are grouped into cluster of 3 cells and each cluster employs all of the frequencies. This means that the capacity is increased by a factor of 7.

Therefore, Capacity = 210 x 7 = 1470 channels

**(c) Explain why the system capacity in (b) is increased, compared with (a). Discuss how to choose the cluster size in a cellular network.**

In the full-duplex mode of operation, a radio channel contains a pair of channel frequencies, each of which is transmitted at a frequency. The radio channel F1 is used to call one cell in the geographical area C1 with the coverage radius R, and F1 can be used again in another cell with the distance D and the coverage radius R.

Theoretically, K should be larger, however, the total number of channels allocated is fixed. If K is too large, the number of channels allocated to each cell in the K cells will decrease, and if the total number of channels in the K cells is divided as K increases, the relay efficiency decreases. Similarly, if a group of channels in the same area is assigned to two different working networks, the system frequency efficiency will be reduced. Therefore, the question now is how to obtain a minimum K value under the condition of satisfying the system performance. To solve it, it is necessary to estimate the co-channel interference and select the minimum frequency reuse distance D to reduce co – channel interference. When the conditions are satisfied, the number of cells constituting the unit radio zone group K = i2 + ij + j2.

**(d) What is link budget analysis in wireless communications? Discuss its applications in wireless communications network deployment.**

When a Signal travels from a transmitter to receiver, there are events like gain and loss during signal transmission through mediums like cable, fiber etc. A Link budget analysis is an account of all such gains and losses. The attenuation of the transmitted signal due to propagation, as well as the antenna gains, feed line and miscellaneous losses are also accounted for. Arbitrarily varying channel gains such as fading are taken into account by adding some margin depending on the anticipated severity of its effects. A link budget equation would look like as follows:

Power Received (dB) = Power Transmitted (dB) + Gains (dB) − Losses (dB)

In practical situations like Deep Space Telecommunications, Weak signal DXing etc. other sources of signal loss must also be accounted for. The transmitting and receiving antennas may be partially cross-polarized. The cabling between the radios and antennas may introduce significant additional loss.

Also, Guided media such as coaxial and twisted pair electrical cable, radio frequency waveguide and optical fiber have losses that are exponential with distance. The path loss will be in terms of dB per unit distance. This means that there is always a crossover distance beyond which the loss in a guided medium will exceed that of a line-of-sight path of the same length. Long distance fiber-optic communication became practical only with the development of ultra- transparent glass fibers. A typical path loss for single mode fiber is 0.2 dB/km, far lower than any other guided medium.

Because of building obstructions such as walls and ceilings, propagation losses indoors can be significantly higher. This occurs because of a combination of attenuation by walls and ceilings, and blockage due to equipment, furniture, and even people.

**Link Budget Applications**

* In communications like Earth-Moon-Earth, link budgets are important. High power and high gain antennas must be used as the path loss is huge over an enormous return distance of 770,000 kilometers.
* The Voyager Program spacecraft have the highest known path loss and lowest link budgets of any telecommunications circuit. Although the Deep Space Network has been able to maintain the necessary technological advances to maintain the link, the received field strength is still very weak.

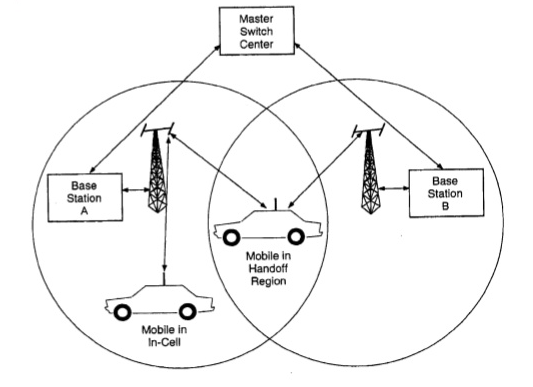
**2. Consider a cellular communication network.**

**(a) Explain the concept of frequency reuse in cellular communication network.**

Frequency reuse is the practice of splitting an area into smaller regions that do not overlap so that each utilizes the full range of frequencies without interference. The introduction of this concept was a major step in the development of mobile phone technology. Before the advent of cellular phones, radio telephones and other mobile communications devices relied on a single, central antenna tower to service an entire city. Each phone required a large antenna powerful enough to transmit a signal over the potentially great distance to that tower. In addition, there was a limit to the amount of phone traffic that could be supported at a given time because each tower only offered a limited number of channels.

After some good amount of research, it was realized that they could increase the cap on the number of simultaneous users by applying their current technology to a smaller scale. Accordingly, they introduced frequency reuse. Mobile communications providers increased the total number of towers and reduced the size of each one's service area. Although each tower had a limited number of channels, the non- overlapping nature of the service areas allowed the same frequency to be used in each one without interference. By doing so, mobile communications providers greatly expanded the number of potential users.

**(b) Explain the need for handoff process in cellular communications and discuss how to choose a proper handoff threshold.**



In Cellular communication, when a mobile user is on a call and travels from one area of coverage or cell to another cell, the call should be transferred to the new cell’s base station. Failing which, the call will be dropped because the link with the current base station becomes too weak as the mobile recedes. This ability for transference in cellular communication is called handoff

Two types of handoff:

**Hard handoff**

With hard handoff, the link to the prior base station is terminated before or as the user is transferred to the new cell’s base station. That is to say that the mobile is linked to no more than one base station at a given time. Initiation of the handoff may begin when the signal strength at the mobile received from base station 2 is greater than that of base station 1. The signal strength measures are really signal levels averaged over a chosen amount of time. This averaging is necessary because of the Rayleigh fading nature of the environment in which the cellular network resides. A major problem with this approach to handoff decision is that the received signals of both base stations often fluctuate. When the mobile is between the base stations, the effect is to cause the mobile to wildly switch links with either base station. The base stations bounce the link with the mobile back and forth. Hence the phenomenon is called ping- ponging.

**Soft handoff**

Soft handoff technology is used by code-division multiple access (CDMA) systems. Older networks use frequency division multiplex (FDM) or time division multiplex (TDM). In CDMA, all repeaters use the same frequency channel for each mobile phone set, no matter where the set is located. Each set has an identity based on a code, rather than on a frequency (as in FDM) or sequence of time slots (as in TDM). Because no change in frequency or timing occurs as a mobile set passes from one base station to another, there are practically no dead zones. As a result, connections are almost never interrupted or dropped.

**Comparison**

Soft handoff is advantageous over hard handoff because the mobile does not lose contact with the system during handoff execution. Ping ponging is eliminated and an extra measure of performance is obtained through diversity combining to mitigate fading. Furthermore, more control may be given to the mobile in handoff decisions. This autonomous handoff decision ability, selection diversity, and inherent improvement of reliable handoffs with fewer unnecessary decisions, make soft handoff an attractive choice meriting further study as it is being used in third generation CDMA.

**(c) Discuss all possible interferences in cellular communications network and their causes.**

Anything which modifies, or disrupts a signal as it travels along a channel between a source and a receiver is called interference. The term typically refers to the addition of unwanted signals to a useful signal. The term typically refers to the addition of unwanted signals to a useful signal. Interference is at least an occasional problem with most types of radio equipment, including wireless microphones. The effects of interference range from being a minor annoyance to making the wireless system completely unusable. Serious interference is not as common as is sometimes assumed, especially when some simple precautions are taken.

Types of interference:

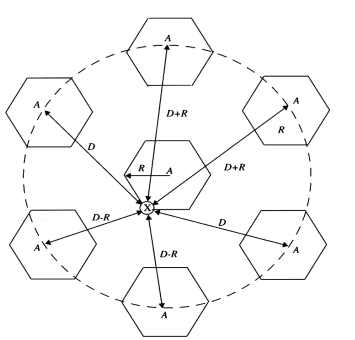
*Radio frequency interference* is caused by radio and TV transmitters, communications equipment, cable television systems and other types of equipment that generate radio frequency energy as part of their operation.

*Electrical interference* is caused by computers and digital equipment, heavy electrical equipment, lighting systems, faulty electrical devices, etc.

*Inter modulation* is a type of interference caused by the internal combination of strong radio signals in wireless receivers.

Simply knowing which type of interference is present helps avoid wasting time on unproductive approaches and greatly simplifies the process of finding the real source of the problem.

**(d) Use the following figure and explain the worst scenario of co-channel interference in cellular communication. Discuss how the frequency reuse ratio of a cellular network is determined. The free space signal propagation model can be used.**



The first tier of co-channel cells for a cluster size of N = 7. When the mobile is at the cell boundary of point X, it experiences worst case co-channel interference on the forward channel. The marked distances between the mobile and different co-channel cells are based on approximations made for easy analysis.

For N = 7, the co-channel reuse ratio Q is 4.6, and the worst-case S/I is approximated as 49.56 (17 dB) whereas an exact solution yields 17.8 dB

Hence for a seven-cell cluster, the S/I ratio is slightly less than 18 dB for the worst case.

To design the cellular system for proper performance in the worst case, it would be necessary to increase N to the next largest size,

This obviously entails a significant decrease in capacity, since 12-cell reuse offers a spectrum utilization of 1/12 within each cell, whereas seven-cell reuse offers a spectrum utilization of 1/7. In practice, a capacity reduction of 7/12 would not be tolerable to accommodate for the worst- case situation which rarely occurs. From the above discussion, it is clear that co-channel interference determines link performance, which in turn dictates the frequency reuse plan and the overall capacity of cellular systems.

**3. Both analog and digital modulation schemes are widely used in wireless communication systems.**

**(a) Explain why modulation techniques are important for wireless communications.**

The modulation process consists of two signals: the modulating signal and the carrier. The modulating signal is nothing but the baseband signal or information signal while the carrier is a high frequency sinusoidal signal. In the modulation process, some parameter of the carrier wave, like amplitude, frequency or phase is varied with respect to the modulating signal. The resultant modulated signal is then transmitted. At the receiver end the received signal is demodulated and gets the original information signal back.

The carrier wave carries the information signal from the transmitter to receiver in the process of modulation. Baseband transmission has many limitations which can be overcome using modulation. The baseband signal is translated i.e., shifted from low frequency to high frequency during modulation. This frequency shift is proportional to the frequency of carrier.

Some advantages of Modulation:

*Increase in range of communication*

The frequency of baseband signal is low, and the low frequency signals cannot travel long distance when they are transmitted. They get heavily attenuated. The attenuation reduces with increase in frequency of the transmitted signal, and they travel longer distance. The modulation process increases the frequency of the signal to be transmitted. Therefore, it increases the range of communication.

*Increase in Range of Communication*

The frequency of baseband signal is low, and the low frequency signals cannot travel long distance when they are transmitted. They get heavily attenuated. The attenuation reduces with increase in frequency of the transmitted signal, and they travel longer distance. The modulation process increases the frequency of the signal to be transmitted. Therefore, it increases the range of communication.

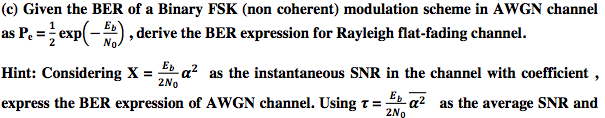
*Prevents mixing of signals*

If the baseband sound signals are transmitted without using the modulation by more than one transmitter, then all the signals will be in the same frequency range. Therefore, all the signals get mixed together and a receiver cannot separate them from each other. Hence, if each baseband sound signal is used to modulate a different carrier then they will occupy different slots in the frequency domain. This is how modulation prevents signals from mixing.

**(b) Discuss the differences between analog and digital modulation principles.**

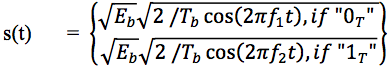
The main difference between analog modulation and digital modulation is in the manner that they transmit data. With analog modulation, the input needs to be in the analog format, while digital modulation needs the data in a digital format. There are differences in the input signal and as a result the output signal is also quite different. In analog modulation, any value between the maximum and minimum is considered to be valid. It is not so with digital modulation as only two values are considered valid; one value to represents 1 and another to represent 0. Everything else is considered as noise and hence ignored. Since most signals that we transmit are analog in nature, like one’s voice, it is far simpler to do analog modulation than digital. If you want to transmit a voice using digital modulation, you’d need to pass it through an analog-to-digital converter before transmission and a digital-to- analog converter at the receiver to recover the original signal. Both the cost and complexity to transmit the signal increases with additional steps of digital modulation.

Digital modulation has greater fidelity over analog transmission. With analog modulation, any noise or interference that falls in the given frequency bandwidth gets mixed with the actual signal. Although there are a number of ways to mitigate noise, it will still cause some amount of degradation. Because digital modulation only recognizes 0’s and 1’s, any noise is virtually eliminated once the receiver discerns whether a “0” or a “1” was transmitted. The output signal will be literally identical to what was transmitted, unless the signal is very badly distorted. There are a number of other modulation techniques under both analog modulation and digital modulation, each with its own strengths and weaknesses. Each technique has its basic commonalities of transmitting either a digital or analog signal.

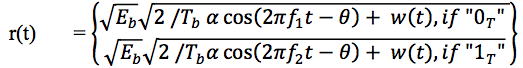
****

../Screen%20Shot%202018-04-10%20at%2011.02.59%20AM.png

Transmitted Signal =

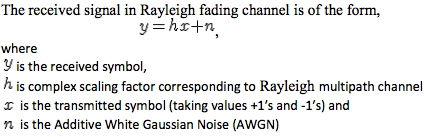


Received signal =



In the following development of the optimum receiver, both the random amplitude,../Screen%20Shot%202018-04-10%20at%2010.50.59%20AM.png and phase../Screen%20Shot%202018-04-10%20at%2010.52.13%20AM.png are completely unknown at the receiver. This type of non coherent demodulation is commonly used due to its simple implementation. If the channel fading is sufficiently slow, then it is possible to estimate the random phase from the received signal.

**../Screen%20Shot%202018-04-10%20at%2011.05.28%20AM.png**

****

The channel is flat fading – In simple terms, it means that the multipath channel has only one tap. So, the convolution operation reduces to a simple multiplication. The channel is randomly varying in time – meaning each transmitted symbol gets multiplied by a randomly varying complex number . Since is modeling a Rayleigh channel, the real and imaginary parts are Gaussian distributed having mean 0 and variance 1/2. The noise has the Gaussian probability density function with

 with  and 

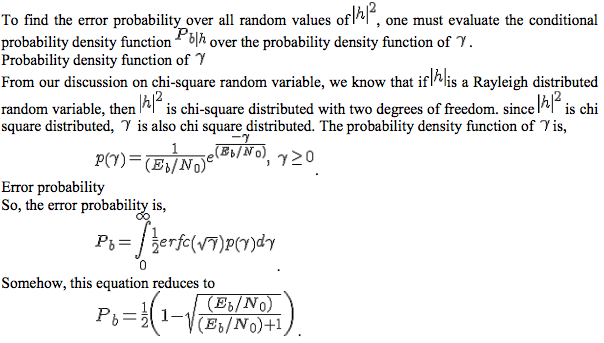
Also, the channel is known at the receiver. Equalization is performed at the receiver by dividing

the received symbol by the apriori known i.e.

 where  is the additive noise scaled by the channel coefficient

Bit Error Rate, If you recall, in the post on BER computation in AWGN, the probability of error for transmission of either +1 or -1 is computed by integrating the tail of the Gaussian probability density function for a given value of bit energy to noise ratio.

The bit error rate: 



../Screen%20Shot%202018-04-10%20at%2011.17.38%20AM.png

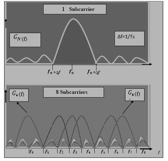
**4. Orthogonal Frequency Division Multiplexing (OFDM) is generally considered as one of the premier transmission technologies for broadband wireless communications.**

**(a) Discuss the general principle of OFDM and its advantages when compared with single carrier modulation.**

Orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication, used in applications such as digital television and audio broadcasting, DSL Internet access, wireless networks, power line networks, and 4G mobile communications. OFDM is a frequency-division multiplexing (FDM) scheme used as a digital multi- carrier modulation method. A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional single- carrier modulation schemes in the same bandwidth.

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters.

Channel equalization is simplified because OFDM may be viewed as using many slowly modulated narrowband signals rather than one rapidly modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate inter symbol interference (ISI) and utilize echoes and time-spreading (on analogue TV these are visible as ghosting and blurring, respectively) to achieve a diversity gain, i.e. a signal-to-noise ratio improvement. This mechanism also facilitates the design of single frequency networks(SFNs), where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single- carrier system.

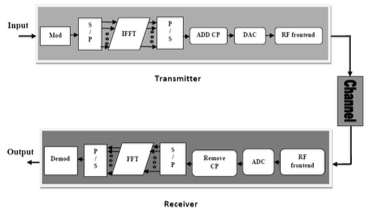


**(b) Draw the block diagram of an OFDM system with FFT/IFFT based modulation/demodulation, in-band pilots and cyclic prefix insertion.**

In OFDM system, here an input data symbols are supplied into a channel encoder that data are mapped onto BPSK/QPSK/QAM constellation. The data symbols are converted from serial to parallel and using Inverse Fast Fourier Transform (IFFT) to achieve the time domain OFDM symbols. Time domain symbols can be represented as:

xn = IFFT {Xk} = 1 2 −1 =0 0 ≤ ≤ N – 1 (1)

Where, Xk is the transmitted symbol on the kth subcarriers N is the number of subcarriers Time domain signal is cyclically extended to prevent Inter Symbol Interference (ISI) from the former OFDM symbol using cyclic prefix



The Digital to Analog Converter (DAC) is performed to convert the baseband digital signal into analog signal. This operation is executed in DAC block of diagram. Then, the analog signal is proceeded to the Radio Frequency (RF) frontend. The RF frontend performs operations after receiving the analog signal. The signal is up converted to RF frequencies using mixer and amplified by using Power Amplifier (PAs) and then transmitted through antennas. At the receiver side, the received signal is down converted to base band signal by RF front end. The analog signal is digitized and resampled by the Analog to Digital Converter(ADC). The ADC is used to digitize the analog signal and re-samples it. In the figure, frequency and time synchronization block are not shown because of simplicity. Cyclic prefix is removed from the signal in frequency domain. This step is done by the Fast Fourier Transform (FFT) block. The received symbols in the frequency domain can be represented as:

Y (k) = H (k) Xm (k) + W (k)- (2) where, Y (k) is the received symbol on the k th subcarrier, H (k) is the frequency response of the channel on the same subcarrier and W (k) is the additive noise added to kth , subcarrier which is generally assumed to be Gaussian random variable with zero mean and variance of 2 .

Thus, simple one tap frequency domain equalizers can be employed to get the transmitted symbols. After FFT signals are deinterleaved and decoded to recover the original signal.

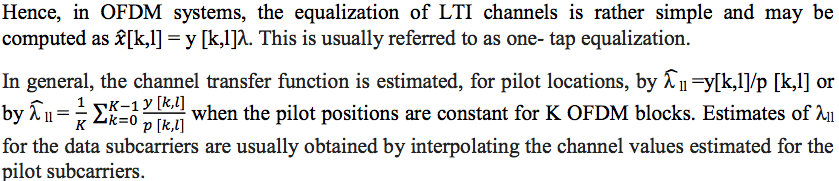
**(c) Explain how equalization is achieved in OFDM system.**

When either the channel time variation is absent, i.e., for LTI multipath channels, or it can be neglected, the channel impulse response (CIR) is constant over time. Hence, becomes [HT[k]]n, m = h[0, (n – m) mod L], i.e., HT [k] = HT is circulant and constant over the OFDM blocks. In this scenario, the CP not only eliminates the ISI, which could be removed by any kind of sufficiently long guard interval, e.g., by trailing zeros. In addition, the CP induces a time – domain circular convolution of the transmitted signal with the CIR, which corresponds to a scalar multiplication in the discrete frequency domain. Because the columns of the DFT matrix, which linearly precodes the OFDM data, are eigenvectors of circulant matrices, the eigenvalue decomposition of HT is given by HT = WH∧ W. Consequently, HF[k] = HF = ∧ is diagonal, which shows that in LTI channels there is no ICI. A continuous – time interpretation of OFDM systems is that, for every OFDM block, the lth symbol is transmitted in the frequency domain by a sinc function centered on the lth subcarrier. The zeros of this sinc function are located on the other equispaced subcarriers, which guarantees ICI – free reception by DFT spectrum sampling. It is easy to derive

../Screen%20Shot%202018-04-10%20at%2012.08.38%20PM.png

i.e., HF contains on its diagonal the DFT of the CIR. Due to the diagonal frequency – domain channel matrix, the input – output relation can be expressed as

../Screen%20Shot%202018-04-10%20at%2012.10.29%20PM.png



**(d) What is Peak-to-average power ratio (PAPR) in OFDM and elaborate on the main problems associated with this.**

The OFDM technique divides the total bandwidth into many narrow sub-channels and sends data in parallel. It has various advantages, such as high spectral efficiency, immunity to impulse interference and, frequency selective fading without having powerful channel equalizer. But one of the major drawbacks of the OFDM system is high PAPR. OFDM signal consists of lot of independent modulated subcarriers, which are created the problem of PAPR. It is impossible to send this high peak amplitude signals to the transmitter without reducing peaks. So, we have to reduce high peak amplitude of the signals before transmitting. A major source for reducing energy costs is to increase the efficiency of the high-power amplifier (HPA) in the radio frequency (RF) front end of the base stations. However, efficiency of the HPA is directly related to the peak-to-average power ratio (PAPR) of the input signal.

The problem especially becomes serious in orthogonal frequency-division multiplexing (OFDM) multicarrier transmission, which is applied in many important wireless standards such as the Third- Generation Partnership Project (3GPP) Long-Term Evolution Advanced (LTE-A) standard.m. The PAPR problem still prevents OFDM from being adopted in the uplink of mobile communication standards, and, besides power efficiency, it canalso place severe constraints on output power and therefore coverage in the downlink. The design challenge In OFDM transmission, many subcarriers (constructively or destructively) add up at a time that causes large fluctuations of the signal envelope; a transmission that is free from any distortion requires linear operation of HPA over a range N times the average power. As practical values of subcarriers are large, these high dynamics afford HPA operation well below saturation so that most of the supply power is wasted with deleterious effect on either battery life time in mobile applications (uplink) or energy cost of network operation (downlink). In practice, these values are not tolerable, and from a technology viewpoint it is also challenging to provide such a large linear range. Hence, the HPA output signal is inevitably cut off at some point relative to the averagepower (clipping level) leading to in-band distortion in the form of intermodulation terms and spectral regrowth into adjacent channels. The effect is illustrated where the distorted OFDM signal and corresponding impact on the signal points are depicted. The PAPR problem brings up several challenges for the system designer: one challenge is to adjust HPA parameters (HPA backoff, digital pre-distortion) in some specific way so that power efficiency is traded against nonlinear distortion, which effects the data transmission on a global scale. How to capture this tradeoff by a suitable metric on a component level is not clear yet. Special HPA architectures such as Doherty and others can help to improve on this tradeoff. We also mention that other design constraints such as costs might prevent specific architectures. A second challenge is to process the baseband signal by peak power reduction algorithms in such a way that the key figures of merit in the aforementioned tradeoff are improved. This alternating procedure makes it apparent that the PAPR problem involves joint optimization of HPA, pre-distortion, and a signal processing unit. This interplay has only been marginally addressed so far, let alone in the context of multiuser systems equipped with multiple antennas such as LTE-A.