

# Soft Defined Radio Communications for Interoperability

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## Topic Area

Security/vulnerability of goods movement

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## Abstract

The current radio systems of port community and needs are studied in this paper. Specifically, Project 25 is briefly discussed along with the interoperability. Department of Homeland Security's levels of interoperability are provided with Project 25. Moreover, the software defined radio (SDR) concepts in conjunction with orthogonal frequency division multiplexing (OFDM) technology are presented as an universal communication architecture for the current and future communication systems, which is

the standard of IEEE 802.11, also known as WiFi. The interoperability among different data rate is performed by using adaptive modulation scheme. It is demonstrated via software simulations in additive white Gaussian (AWGN) and flat Rayleigh fading channels of multipath environment. Note that flat Rayleigh fading channels are the typical communication channels at the Ports Long Beach and Los Angeles areas.

## **1. Introduction**

Although radio interoperability has improved greatly since the events in 1982 [1], interoperability issues still exist. This paper presents the current communication systems used by public agencies and to determine the future communication requirements. In the first section, the current radio systems are analyzed with the focus of determining the most important problems with the system today. This includes a brief look into the progress of the interoperability initiative, Project 25 (P25), as well as other proposed changes/improvements to the radio system.

The subsequent sections are a preliminary study for a future radio system. This includes a software-defined radio and a fast-growing technology known as orthogonal frequency division multiplexing (OFDM). OFDM has been around for awhile in other applications and is recently being developed as a wireless broadband solution, such as worldwide interoperability for microwave access (WiMAX), also known as IEEE802.16. These sections deal with some of the major challenges of implementing OFDM technology on the mobile radio side. This includes maintaining the BER requirement through adaptive modulation and the reduction of peak-to-average power ratio (PAPR) in OFDM signals.

## **2. The Current Radio System and Needs**

### **2.1 The Current Radio System**

From our surveys conducted in 2006 [2], the radio systems used by agencies date back to the 1980s. The current radio systems used by the public safety agencies have many modes of operations. This includes analog, digital, and trunked modes. There are also many frequency bands used for communication such as UHF, VHF, 800 MHz. An additional issue is vendor incompatibility due to proprietary technology.

Another factor is the assortment of frequency bands allocated for public safety. As of 2003, there were thirteen frequency bands available including VHF-low, VHF-high, UHF( (low, T-band), 700 MHz, 800 MHz, and NPSPAC. This introduces issues

because the frequencies require hardware tuned for those frequencies, so radios operating on one frequency will not work on another frequency.

Proprietary technology is another hurdle towards interoperability. One of the older problems towards interoperability was the lack of standards, which is an issue due to multiple vendors. An introduction of standards to create a basic foundation on which to design and operate radios helps with proprietary technology. Basically, one creates units of black boxes so that the input and output to that black box are consistent, so it doesn't matter who or how the black boxes are created so as there are the same number of inputs and outputs use the same known input and output type.

Since there are many agencies using radio systems spanning many levels of government including federal, tribal, state, county, and local; there are many systems in use. This makes interoperability a challenge in terms of defining standards, selecting technology and equipment, and non-technological aspects such as planning and implementing changes to the radio systems.

## **2.2 Project 25 – Standards for Interoperability**

Endorsed by public safety agencies, Project 25 provides standards for many radio interfaces such as the inter-RF subsystem, air, console subsystem, and fixed station interfaces. Some of the key problems it tries to solve are equipment interoperability through backward/forward compatibility and digital standards, vendor compatibility, and improved spectrum efficiency. It is also concerned with smooth migration between technologies and it is based on open standards to prevent vendor lock-in and encourage competition for the best products and the lowest prices. P25-compliant technology is being deployed in several phases, based on Telecommunications Industry Association (TIA) engineering committee work and the P25 standards TIA publishes.

Vendors are currently shipping Phase I P25 compliant systems. These systems involve standardized service and facility specifications, ensuring that any manufacturer's

compliant subscriber radio has access to the services described in such specifications. Abilities include backward compatibility and interoperability with other systems, across system boundaries, regardless of system infrastructure. In addition, the P25 suite of standards provides an open interface to the radio frequency (RF) subsystem to facilitate interoperability of different vendors' systems.

P25 Phase II implementation involves time and frequency modulation schemes, with the goal of improved spectral efficiency. Significant attention is also paid to interoperability with legacy equipment, interfacing between repeaters and other subsystems, roaming capacity and spectral efficiency/channel reuse. In addition, Phase II work involves console interfacing between repeaters and other subsystems, and man-machine interfaces for console operators that would facilitate centralized training, equipment transitions and personnel movement.

Recognizing the need for high-speed data for public-safety use, as expressed in the Public Safety Wireless Advisory Committee (PSWAC) Final Report, the P25 standard committee established the P25/34 committee to address Phase III implementation. Phase III activities are addressing the operation and functionality of a new aeronautical and terrestrial wireless digital wideband/broadband public safety radio standard that could be used to transmit and receive voice, video and high-speed data in a ubiquitous, wide-area, multiple-agency network. Due to common needs, the European Telecommunications Standards Institute (ETSI) and TIA will work collaboratively for the production of next-generation mobile broadband specifications for public safety users. This international collaboration is known as Project MESA (Mobility for Emergency and Safety Applications). Current P25 systems and future Project MESA technology will share many compatibility requirements and functionalities [3].

### **2.3 Levels of Interoperability**

There is a move to provide interoperable communication defined as the “ability for public safety first responders to communicate with whom they need to, when they

need to, when authorized.” The ability to provide interoperable communication is not strictly dependent on technological solutions, although it is the most obvious segment to providing interoperability.

According to the DHS, there are six levels of interoperability based on scale and complexity. They are radio swapping, talkaround, mutual aid channels, gateway consoles, system specific roaming, standards based shared systems.

Radio swapping is the physical exchange of radios between the agencies. This is the simplest form of interoperability, but is impractical for large scale events involving many agencies/officials. Talkaround is the direct communication between radios and its successful use is dependent on the air interface used by the radios involved. Both radio swapping and talkaround are simple solutions best suited for small scale events.

Mutual aid channels are designated channels in a frequency band such as VHF, UHF, or 800 MHz. Implementation of mutual aid channels requires dedicated infrastructure and spectrum. This allows first responders to communicate on the designated channel in areas with RF coverage.

Operability between frequency bands is achieved by linking radio systems. There are several methods to link radio systems, including fixed gateways, field deployable gateways, and cross-band repeaters.

The next level of interoperability is system specific roaming. This is analogous to cellular system roaming, allowing radios to operate when outside of the home system/coverage area.

The final level of interoperability is standards based shared systems. This revolves around standardization of equipment so that any system based on the standards can be inserted into the network with functionality with all other radios currently in the network. The purpose of this is large scale, seamless coverage and Project 25 is the set of

standards in development for the digital land mobile radio system. Table 1 shows the levels of interoperability defined by the Department of Homeland Security (DHS) and a brief description of their impact. The state of interoperability in California is provided in [4].

Table 1 - Department of Homeland Security’s levels of interoperability.

<i>DHS levels of Interoperability</i>		
<b>Level</b>	<b>Method</b>	<b>Description</b>
6	Standards-based shared systems	Most complete long term solution
5	System Specific Roaming	Full featured wide area
4	Gateway Console	Short-term system modification
3	Mutual Aid Channels	Widespread use with public safety agencies
2	Talkaround	Short-term simple solution
1	Radio swap	Short-term simple solution

#### **2.4 Non-technological Aspects of Interoperability**

Implementing and advancing the level of radio communication interoperability in a region is a challenging endeavor and requires overcoming non-technical obstacles. Some of the commonly listed requirements for successfully implementing interoperability include planning, leadership, partnership, funding, and practice.

The essential component is comprehensive planning, which is needed to develop the necessary policies, procedures, and to determine best practices. Leadership is stressed through the creation of a governance to guide all agencies involved towards a common goal. Multi-agency partnership is important for successful interoperable implantation, since the goal is to bring the agencies together. This ensures all agencies, regardless of size have input to the process, which includes the need to select technologies. Partnership is important to sharing costs as the radio systems may not be affordable to all agencies. Regular practice of the procedures required for interoperable communication is essential so that they are not forgotten when needed.

#### **2.6 Old Radios and New Equipment**

A major concern here is the basic operability of radios. In some agencies, radios date back to the 1980's and some may date back further. Many of these radios have been in operation for much longer than their expected lifespan. Obsolescence is another factor associated with older radios. Older radios may not be supported anymore by the manufacturers and other radios may not adhere to current FCC technical requirements. For this reason, new equipment is needed and primary requirements for public safety communications are voice communication, reliability, coverage, interoperability, cost efficiency, high data rates, spectral efficiency and security.

Coverage issues can occur because of damaged infrastructure due to a natural disaster, lack of infrastructure in remotes regions, high system usage due to a large multi-agency response, or poor reception due to physical location such as tunnels. Equipment needed for this issue revolved around mobile infrastructure. This includes mobile gateways and repeaters, which is needed in urban areas to provide enhanced in-building, tunnel, and subway coverage. Mobile equipment is also useful as repeaters for regions with poor coverage [5]. For procurement of new radios, P25 compliant radios are currently purchased. The downside to P25 compliant radios is that they are more expensive since they have backward compatibility built-in.

Considering the public safety communications requirements for high spectral efficiency and high data rates, an alternative system is proposed in the next section, based on orthogonal frequency division multiplexing (OFDM) signaling and adaptive modulation. High spectral efficiency is desirable because the spectrum is a limited resource and it is congested, even with another band opening up for public safety agencies. A goal for standards development is to make the most efficient use of the spectrum as possible and a technique that is efficient is OFDM. Improved data rates can be achieved through a combination of technology and advanced techniques to improve signal quality such as adaptive modulation and power control as mentioned in IEEE802.16.

The prevalence of many different radio networks and constantly evolving technology raises the question of whether mobile radios can be used that are not limited to a single network or technology. This would allow a radio operator to operate on theoretically any type of network and allows flexibility to upgrade the radio as newer technology comes out. This is where software defined radio (SDR) comes in and this possibility is explored as well.

### **3. Software-defined Radio for Improving Interoperability**

#### **3.1 SDR Transceiver Architecture**

The idea behind software radio is to move from hardware to software components to increase the design and operating flexibility of a radio system through programmability. Software defined radio basically refers to a set of techniques that permit the reconfiguration of a communication system without the need to change any hardware system element. The goal of software defined radio is to produce communication devices capable of supporting different services. These terminals must adapt their hardware in function of the wireless networks. In fact, this adaptation should be dynamic, more or less in real time [6-9].

The basic functional components of software radio architecture include the power supply, antenna, multiband RF converter, analog-to-digital (ADC) and digital-to-analog converters (DAC), a general processor, and memory. Software radios aim to place the analog-to-digital and digital-to-analog conversion as close to the antenna as possible and perform radio functions in software. Software radio aims to move the dependency of frequency band, channel bandwidth, channel coding, and modulation from hardware to software. The general architecture of the SDR transceiver is shown in Figures 3.1-3.2. Figure 3.1 shows the software reconfigurable transmitter block diagram. Figure 3.2 shows the software reconfigurable receiver block diagram.

The benefits of SDR for the radio system end-users are the co-existence, dynamic configurability, and connectivity of the radios. SDR allows equipment to operate in different standards by selecting the appropriate software. It facilitates smooth transition

between future technology, multiple vendors, modes, bands, and other infrastructure standards.

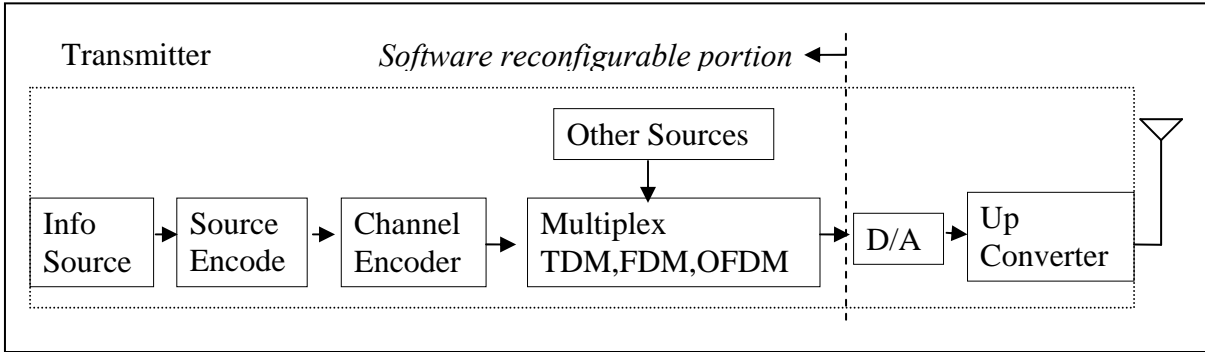


Figure 3.1. Software reconfigurable transmitter block diagram.

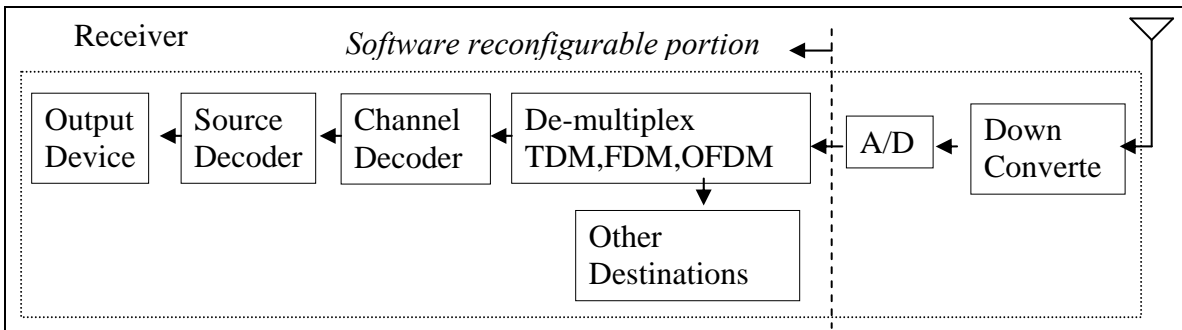


Figure 3.2. Software reconfigurable receiver block diagram.

SDR does not allow simultaneous use of different standards. It gives flexibility to switch over to a standard being used, which facilitates transitions between radio technologies and standards. For example, base stations implementing SDR technology can be inserted today and programmed to operate on frequencies, bandwidths, and modes currently used. When sufficient progress has been made in upgrading a local/regional network, then they can be easily reprogrammed to operate using different standards or technology.

Multi-mode operation is a desirable trait in mobile systems because it also opens the possibility for global roaming with a change in software which could be downloaded from a library of standards. In order for global roaming to be effective, system standards

would have to be accessible so that a library of software downloads could be established for every radio system. Additionally, knowledge of the type of system used in any particular region is needed, so that the correct system software can be installed on the mobile radio. A SDR could then be used, if authorized, to communicate on any standard and on any network which has been fully defined in software.

### **3.2 General SDR Processors**

Software-defined radios can be implemented on several types of architecture which vary according to processing power and flexibility. This includes digital-signal processors (DSP), field programmable gate arrays (FPGA), and applications-specific integrated circuits (ASIC).

## **4. OFDM with Adaptive Modulation**

### **4.1 OFDM**

OFDM is a technique applied to wireless local area networks (WLAN). The incorporation of OFDM techniques in wireless technology continues with the development of standards for wireless metropolitan networks (WMAN) and IEEE 802.20 for mobile wireless connectivity. Hence it is employed in this study as the universal communication technology for interoperability among different data rate.

OFDM is a multi-carrier modulation scheme [10-13], which uses a large number of closely spaced (in the frequency domain) orthogonal sub-carriers. The technique splits a serial block of data into parallel blocks in order to transmit the parallel blocks on individual, orthogonal sub-carrier frequencies. Each sub-carrier is modulated at a lower symbol rate, but the overall data rate of an OFDM channel maintains the data rate of a single carrier channel with the same bandwidth. Figure 4.1 shows a simple OFDM transmitter block diagram. Figure 4.2 shows a simple OFDM receiver block diagram. Note that the baseband operation of the transmitter and receiver is done by using reconfigurable software. Figure 4.3 shows the spectra of a single subchannel, and Figure 4.4 shows the spectra of an OFDM signal waveform with a total of six subchannels. Note

that the OFDM is a spectrally efficient waveform since the spectra of each subchannel overlap as depicted in Figure 4.4.

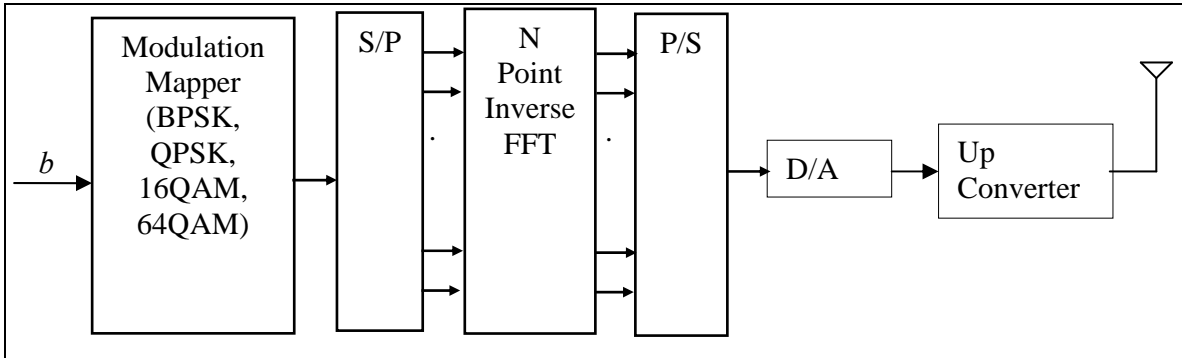


Figure 4.1. Simple OFDM transmitter block diagram.

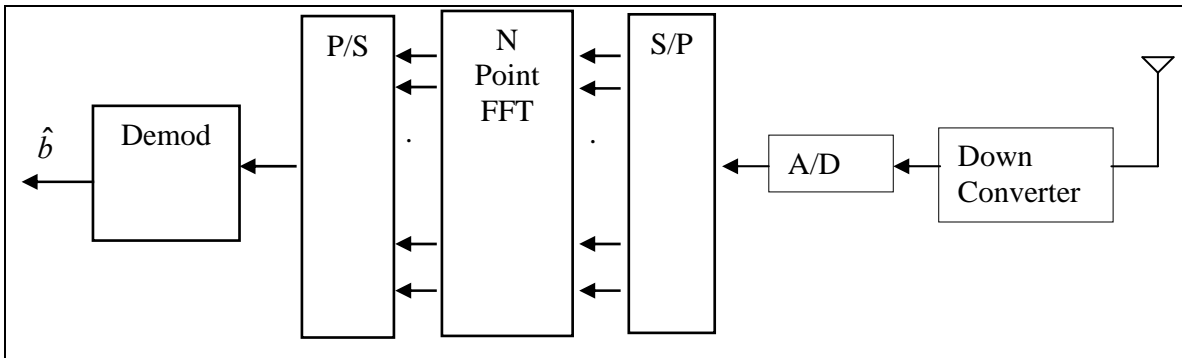


Figure 4.2. Simple OFDM receiver block diagram.

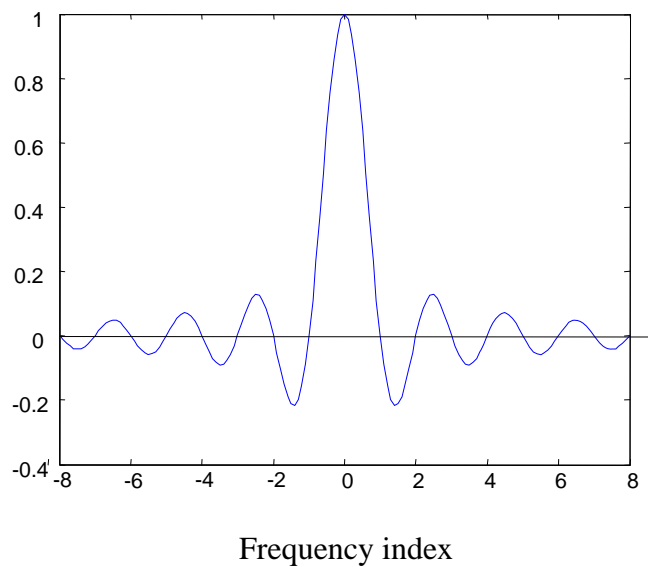


Figure 4.3. Spectra of a subchannel.

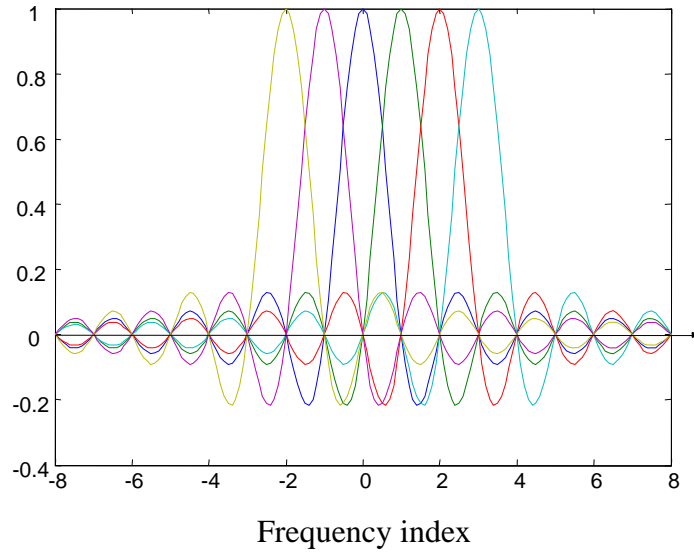


Figure 4.4. Spectra of an OFDM signal.

There are many advantages to implementing an OFDM system, which are relevant to the future needs of the radio systems. OFDM has high spectral efficiency since the spectra of each sub-carrier within an OFDM spectra are designed to overlap, while maintaining orthogonality as depicted in Figure 4.4. Another benefit of OFDM is that it is easily and efficiently implemented in software with the fast Fourier Transform (FFT) algorithm. Additionally, OFDM signals perform better in multi-path fading environments without complex equalizers compared to narrowband signals. These benefits lead us to research OFDM systems as a candidate for future radio systems. The research focuses on preliminary studies of base-band signaling methods and architectures. In the next two sections, we demonstrate the interoperability among different data rate by using the link adaptive for different modulation schemes.

## **4.2 Link Adaptation**

A tool for increasing the spectral efficiency and data rates for wireless networks is link adaptation. This involves changing the modulation, coding rate, and other transmission parameters according to channel conditions. The basic idea of link adaptation defines a set of variable parameters as a selectable mode for a measured signal quality. There are three basic steps to link adaptation which are channel quality

estimation, adaption selection, and adaptation. Adaptive modulation and coding techniques is a currently implemented link adaptation scheme in the cellular standard Enhanced Data GSM Evolution (EDGE).

Challenges associated with the implementation of link adaptation include determination of adaptation thresholds, adaptation rate, and feedback. Adaptation thresholds are determined through simulations or measurements and accurate calculation is difficult, so there is a trade-off between calculating the least amount of statistical channel information and adequately representing the channel characteristics [14].

Degrees of freedom in adaptive modulation refer to the number of parameters that are available for adaptation. As mentioned earlier, adaptive modulation involves varying parameters such as modulation scheme, transmission power, or coding rate. Chung and Goldsmith [15] demonstrated that by restricting power or rate of adaptive modulation, near optimal performance can be achieved.

### **4.3 BER Requirement and Adaptive Modulation**

Adaptive modulation is the on-the-fly changes to modulation scheme and transmit-power to satisfy instantaneous propagation conditions, interference scenarios, or traffic and data rate requirements. Adaptive modulation effectively improves BER, so we look into various modulation techniques with OFDM including  $M$ -ary PSK, differential  $M$ -ary PSK, and QAM for waveforms ranging from  $M=2$  to 64 and perform OFDM simulations for these modulation techniques in AWGN and Rayleigh fading channels to gather performance data. Data from these simulations can be used to define criteria modulation types for specific channel conditions. Figure 4.5 shows BER for  $M$ -ary PSK modulation schemes in AWGN channel. Figure 4.6 shows BER for  $M$ -ary PSK modulation schemes in flat Rayleigh fading channels. Clearly, the higher data rate (i.e.  $M$  is larger) requires higher transmission power in order to achieve the same BER.

To simplify the receiver circuit, differential modulation techniques may be applied to avoid the channel estimation. Furthermore, both 16 and 64 differential amplitude and phase shift keying (16DAPSK and 64DAPSK) are studied. The constellation diagram of 16DAPSK is shown in Figure 4.7. In this case, the data sequence is divided into 4 bits per symbol. The first bit  $b_0$  is for differential amplitude modulation and the rest three bits  $b_1b_2b_3$  are for differential phase modulation. Therefore, differential 16DAPSK is a combination of D-8PSK and 2DASK. In simulation, the ring ratio is chosen as 2.0. Similarly, for 64DAPSK, the data sequence is divided into 6 bits per symbol. The first two bit  $b_0b_1$  is for differential amplitude modulation and the rest four bits  $b_2b_3b_4b_5$  are for differential phase modulation. Therefore, 64-DAPSK is a combination of D-16PSK and 4DASK. In simulation, the ring ratio is chosen as 1.4 for 64DAPSK.

Fig. 4.8 shows BER for differential  $M$ -ary PSK modulation schemes in AWGN channel. Note that both 16DAPSK and 64DAPSK are compared to D-16PSK and D-64PSK in Fig. 4.8. It shows that the BER performance of 16DAPSK and 64DAPSK is better than that of D-16PSK and D-64PSK by 1.7 dB and 6.3 dB, respectively, at BER =  $10^{-5}$ . Fig. 4.9 shows BER of  $M$ -ary PSK modulation schemes in flat Rayleigh fading channels. Similarly, it shows that the BER performance of 16DAPSK and 64DAPSK is better than that of D-16PSK and D-64PSK by 1.7 dB and 6.3 dB, respectively, at BER =  $10^{-2}$ .

Both 16 and 64 -QAM are studied. Furthermore, differential 16 and 64 -QAM (D-16QAM and D-64QAM) are also studied for comparison. Figure 4.10 shows BER performance of 16-QAM, 64-QAM, D-16QAM, and D-64QAM in AWGN channel. Note that the BER performance of 16 and 64 -QAM is better than that of D-16QAM and D64-QAM by about 0.3 dB at BER =  $10^{-5}$ . Figure 4.11 shows BER performance of 16-QAM, 64-QAM, D-16QAM, and D-64QAM in flat Rayleigh fading channel. Note that the BER performance of 16 and 64-QAM is better than that of D-16QAM and D-64QAM by about 4 dB at BER =  $10^{-3}$ .

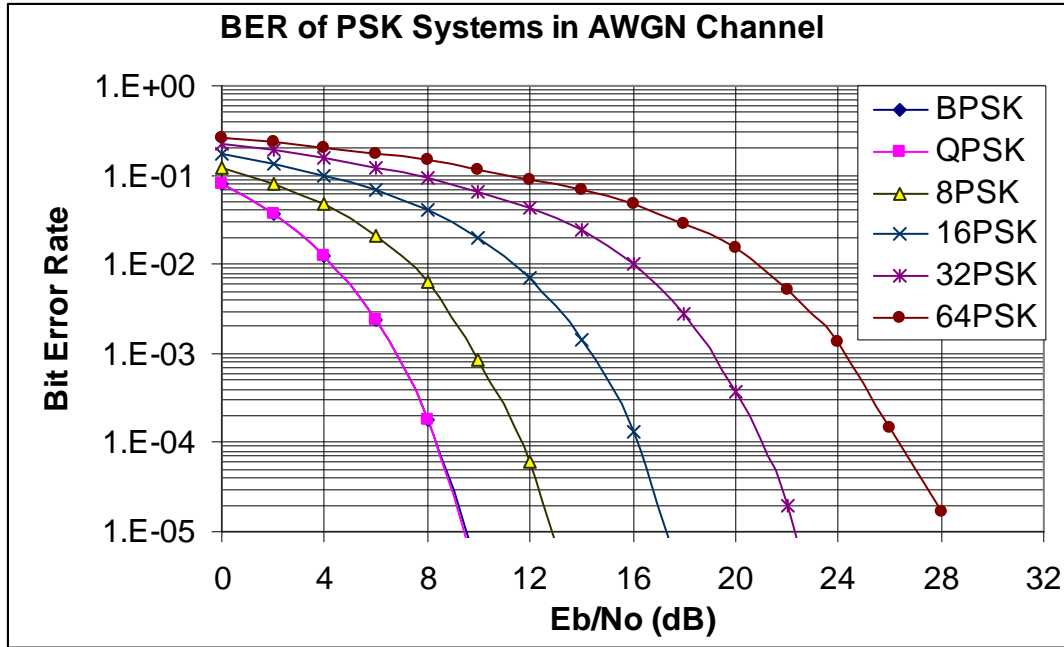


Figure 4.5. BER for  $M$ -ary PSK modulation schemes in AWGN.

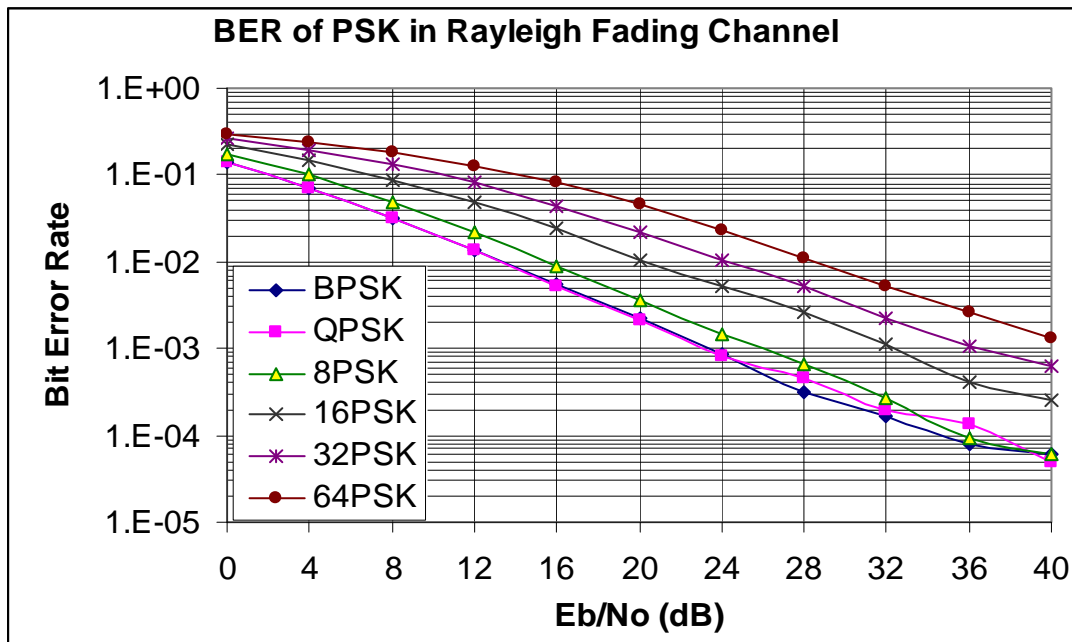


Figure 4.6. BER for  $M$ -ary PSK modulation schemes in a fading channel.

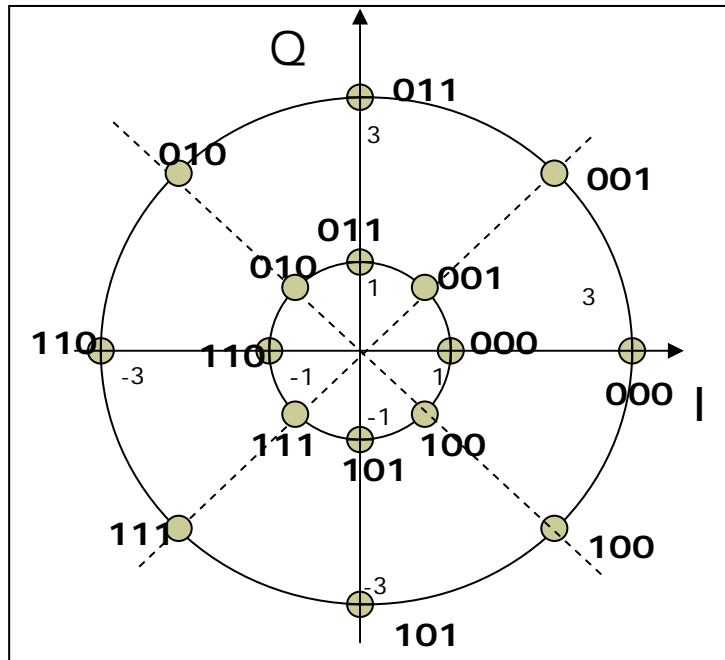


Figure 4.7. Constellation diagram for 16DAPSK.

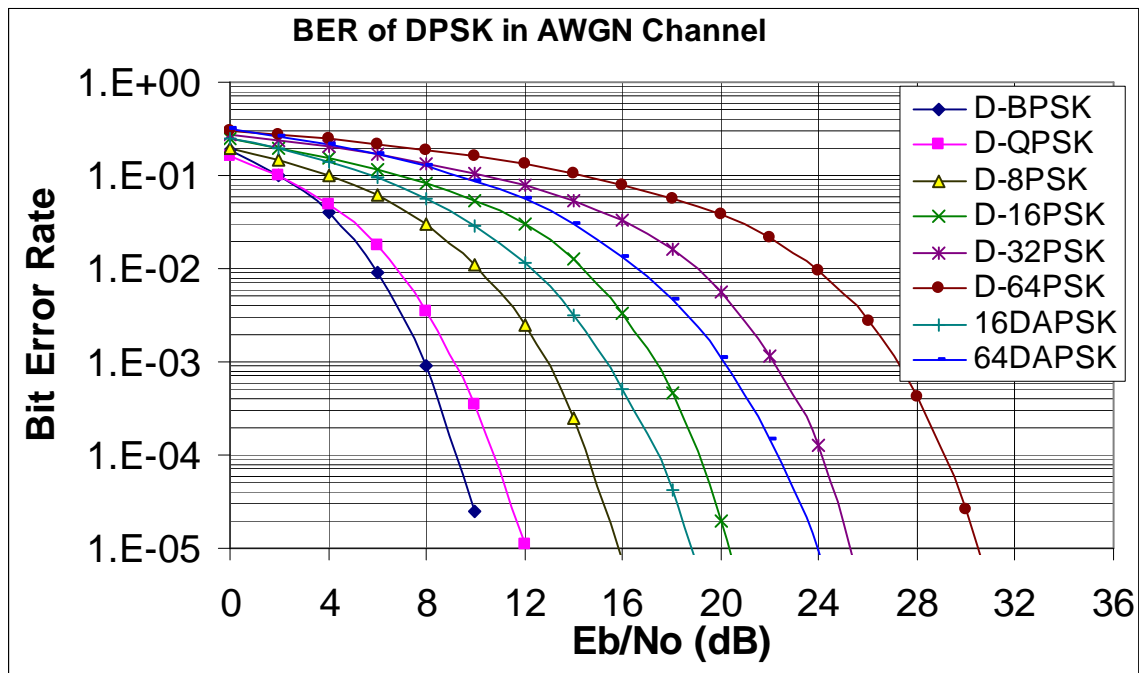


Figure 4.8. BER for DPSK and DAPSK modulation schemes in AWGN.

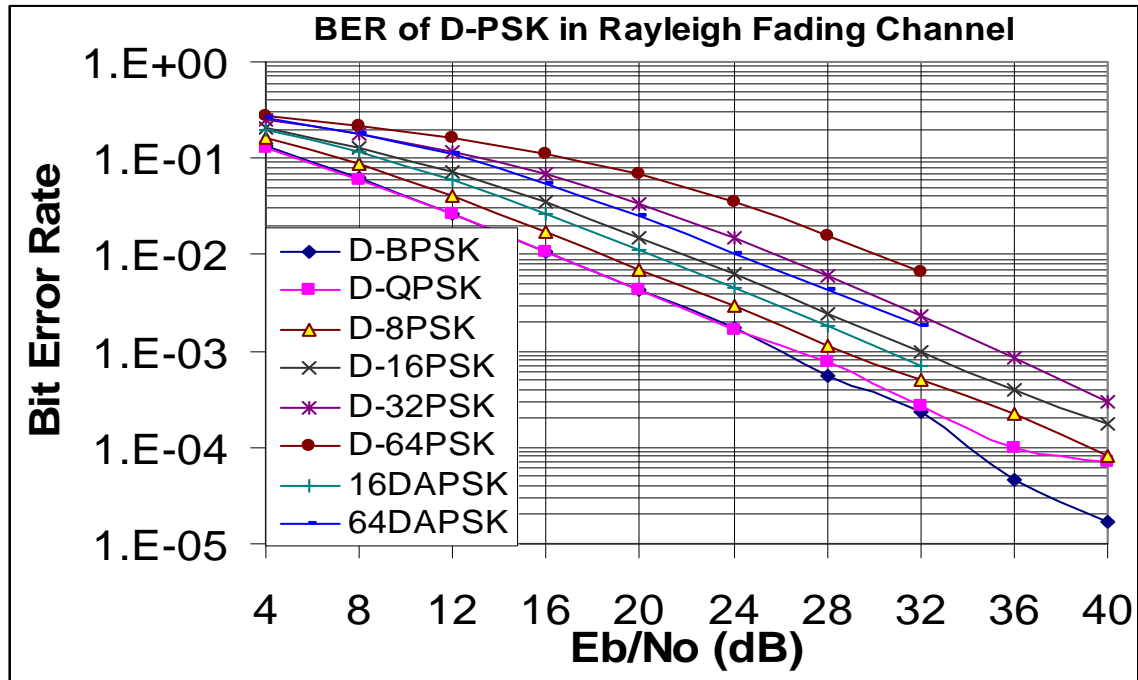


Figure 4.9. BER for DPSK and DAPSK modulation schemes in a fading channel.

The performance for each channel degrades as the number of waveforms per modulation type increases. This is indicated by the higher  $E_b/N_0$  required in maintaining the same BER as the waveforms increase. In comparing the modulation types PSK, DPSK, and QAM, the graphs demonstrate the performance of PSK is better than DPSK. The graphs also show that QAM performance is better than PSK performance for the same number of waveforms. Additionally, the performance relationship between the modulation types hold for both AWGN and Rayleigh fading channels.

Here BER data is used to determine the modulation type and number of waveforms to use for any particular channel condition. As mentioned earlier, desired threshold BER is chosen for a transmission type and as measured channel conditions change, the modulation type changes to maximize the data rates while maintaining the similar BER performance. For example, as a mobile station moves further from a base station, the  $E_b/N_0$  will decrease and consequently, the BER will increase. Therefore, two options are available to increase the  $E_b/N_0$ . The first is to increase transmit power, and

the other is to change the modulation type from a high throughput modulation scheme such as 64-QAM to a lower rate scheme such as BPSK.

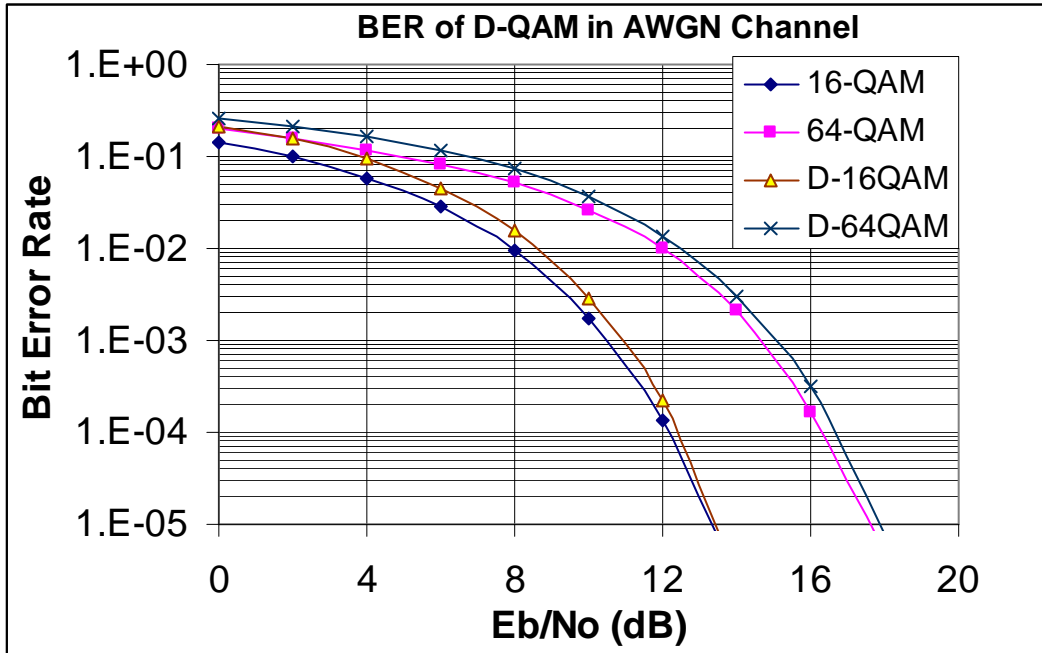


Figure 4.10. BER for QAM and DQAM modulation schemes in AWGN channel.

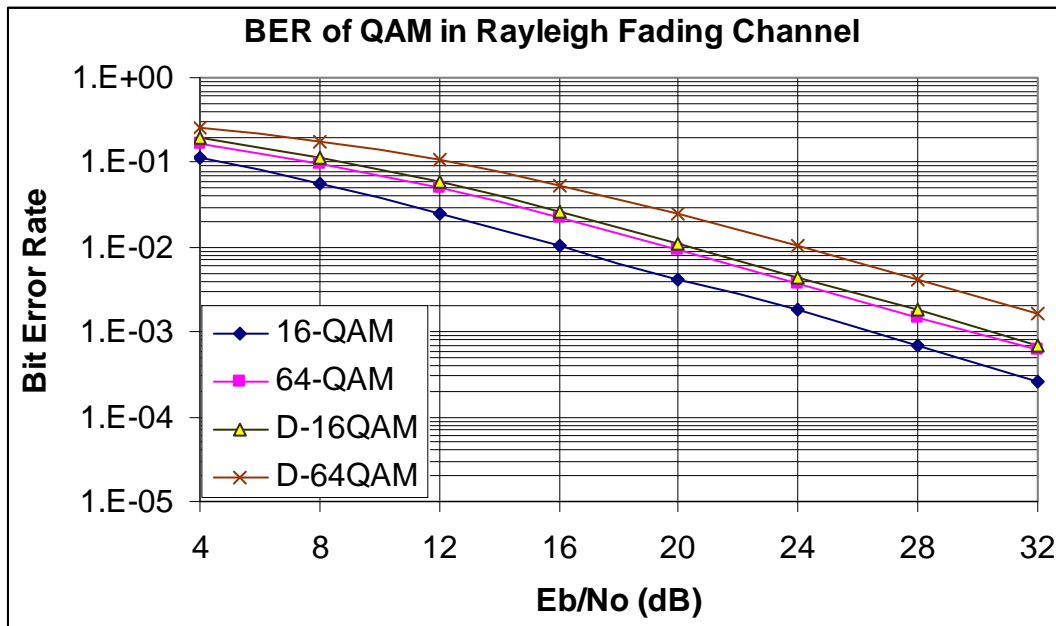


Figure 4.11. BER for QAM and DQAM modulation schemes in a fading channel

Although there are many advantages to implementing OFDM systems, there are a few obstacles to overcome. Two primary issues with OFDM are its frequency offset sensitivity and its high peak-to-average power ratio (PAPR). The frequency offset estimation and related topics are given in [5-8]. Here we focus the discussion on the PAPR reduction and related solution.

## 5. PAPR Reduction

OFDM signals are a parallel transmission of signals over several frequencies and as a result, the signals can coherently add up resulting in large peak-to-average power ratios. This is undesirable because it decreases the power efficiency of transmission. In order to compensate for the high peak to average power, either a highly linear amplifier is needed or clipping of the high peaks occurs reducing the system performance.

There have been several methods suggested to remove peaks including amplitude clipping, tone reservation, tone injection, partial transmit sequences (PTS), selective mapping (SLM), and active constellation extension. The common element to all these techniques is the change in phase of individual subcarrier transmissions to reduce any large peaks. The techniques studied are the PTS and sign flipping method proposed by Sharif.

The commonly used measure of performance for PAPR is the CCDF which is the measure of the probability the PAPR of an OFDM symbol exceeds a given threshold. We have the performance for an unmodified OFDM symbol, a PTS technique, and Sharif's sign flipping technique. Figure 4.12 shows the PAPR reduction with the PTS technique.

Partial Transmit Sequences technique divides the input data of size  $Y$  into  $X$  blocks. Complex phase factors  $b_m = e^{j\varphi^m}$  ( $m = 0, 1, \dots, W-1$  where  $W$  is the number of allowed phase factor) are introduced to rotate the phase of an entire block of data to reduce the PAPR. The number of blocks and the number of allowed phase factors increases the complexity and PAPR reduction ability. In order to get the optimal PAPR

per OFDM symbol, all possible subcarriers and phase rotations must be tested. Currently there is no way to do this faster than testing each scenario. Blocking the data reduces the complexity by lumping subcarriers into groups and testing phase rotations on those groups. One method used to reduce the search complexity is to limit the phase rotations to two possibilities. This is used in the tested PTS method. For a given OFDM symbol, the PAPR is tested and if it exceeds the given threshold, then PTS is implemented. Starting with the second block, the phase of all data subcarriers within that block is rotated and the PAPR is tested to see if it falls below the threshold. If it doesn't then each successive block is phase rotated, PAPR tested, and the rotation with the lowest PAPR is kept. This is done until the PAPR falls below the threshold or all blocks of data have been tested [16].

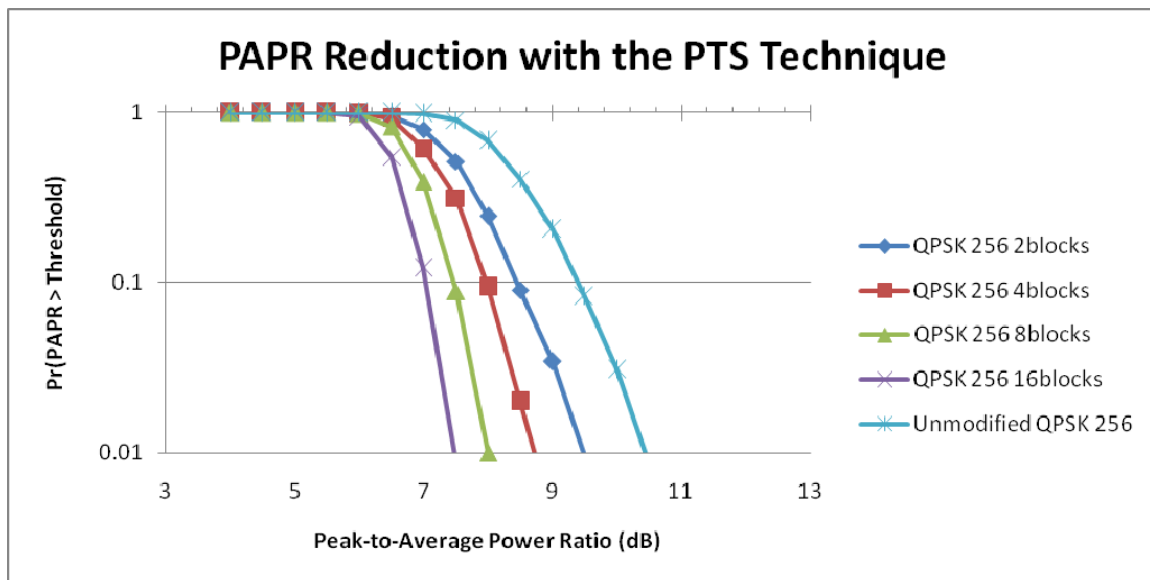


Figure 4.12. PAPR Reduction with the PTS Technique.

The PAPR reduction performance of the PTS technique is dependent on the number of sub-blocks used. For each doubling of the number of sub-blocks, the PAPR reduction is approximately 0.75 dB. However, sub-block addition increases the maximal number of iterations possible per OFDM symbol resulting in more computations per symbol.

Sharif’s method flips the sign of sub-carriers to reduce the PAPR. The deterministic algorithm proposed by Sharif is based on a de-randomization of the search for the sign vectors. This is based on de-randomization of random algorithms and it basically optimizes the search for optimal signs of each subcarrier, instead of testing each possible vector of signs for the best PAPR [17]. Figure 4.13 shows the plot of PAPR reduction with the de-randomization method. The downside of this method is the inability to send information in the signs for BPSK and requires the implementation of another method for BPSK using dummy subcarriers to reduce the PAPR. Another drawback for this method is its computational complexity, which increases as the number of sub-carriers increase. The reason for this is that it does not exploit the efficient calculations of IFFT to create the OFDM signals. However, it reduces PAPR by about 4dB to slightly over 6dB for  $\Pr(\text{PAPR} > \text{threshold})$  of 0.01. This method works effectively on QPSK and 16QAM modulation schemes.

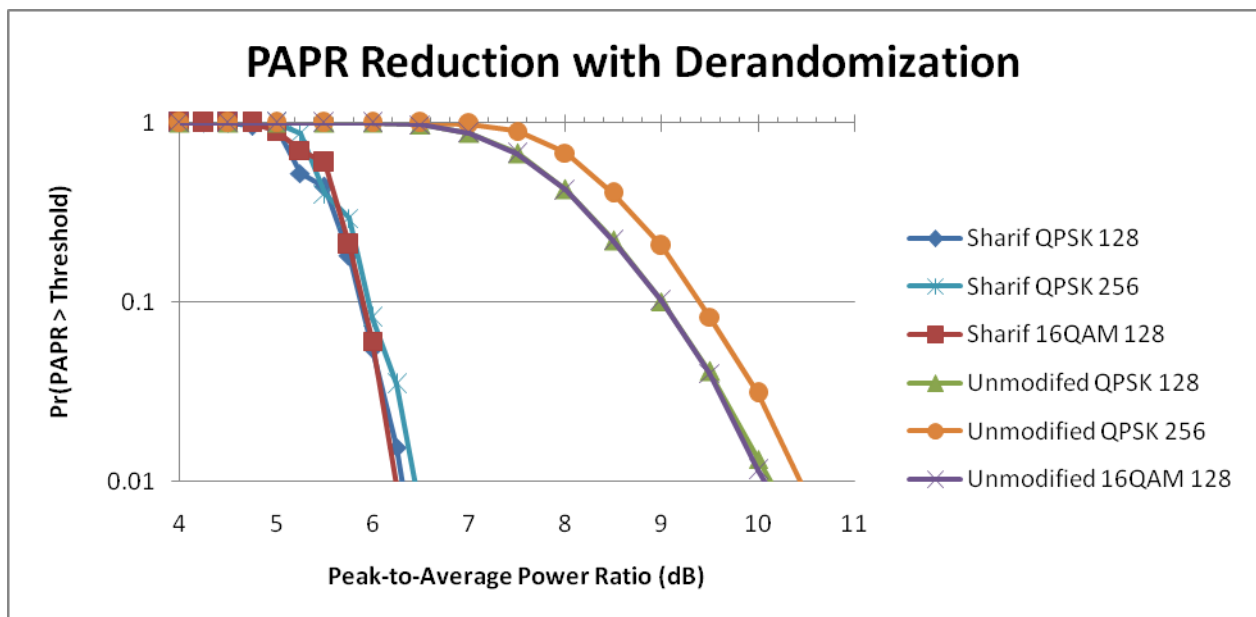


Figure 4.13. PAPR Reduction with the De-randomization Method.

## 6. Conclusion and Recommendations

From a technological standpoint, P25 compliant radios are based on standards to ensure backward compatibility, vendor compatibility, future interoperability, to reduce equipment costs, and increase spectral efficiency. These radios are the choice for public safety agencies in the region and it is recommended that they continue with that policy.

Other equipment that is important to expand coverage is the use of mobile gateways/transceivers to bring radio coverage outside of the home region or to increase building/tunnel penetration.

Alternative solutions for interoperable radios presented are based on software-defined radios, orthogonal frequency division multiplexing, and adaptive modulation. As processing power increases, software-defined radios become more realizable than ever. A reconfigurable architecture opens the door for interoperable communications on multiple standards and networks, presenting the opportunity for wide-scale roaming. For OFDM adaptive modulation, bit error rates were simulated for varying modulation types including M-ary PSK, DPSK, QAM, and DQAM. As M increases from 2 to 64, the performance degrades in both AWGN and Rayleigh fading channels, but this data provides the framework for setting parameters of adaptive modulation. One of the downsides to OFDM is high peak-to-average power ratio, and two methods are simulated here. The partial transmit sequences method with iterative sign flipping demonstrates good PAPR reduction as the number of blocks increases, approaching the reduction provided by the de-randomization method proposed by Sharif. While, the PTS method does not have the best PAPR reduction, it is significantly faster to compute since it takes advantage of the efficient IFFT algorithm.

Further research would expand on the BER rates given here for the various modulation types to test throughput increases of adaptive modulation. To further the PAPR reduction, algorithms that enhance the search for optimal signs while implementing the IFFT algorithm are ideal for study to both reduce the PAPR and preserve low computational complexity.

Additional topics related to OFDM signaling include multiple-input multiple-output (MIMO) communication and related issues such as sensitive frequency synchronization [18]. More study is needed, specially, for the interoperability for the high performance MIMO OFDM areas.

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