Reliable and Covert Satellite Communication Reverse Link

A Project Report

submitted by

NIKITA TANWAR

in partial fulfilment of the requirements
for the award of the degree of

MASTER OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY MADRAS.

JUNE 2020

THESIS CERTIFICATE

This is to certify that the thesis titled **Reliable and Covert Satellite Communication Reverse Link SUBMITTED TO IIT-M**, submitted by **NIKITA TANWAR**, to the Indian Institute of Technology, Madras, for the award of the degree of **MASTER OF TECHNOLOGY**, is a bona fide record of the research work done by her under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Research Guide
Professor Dr.K.Giridhar
Dept. of Electrical Engineering
IIT-Madras, 600 036

Place: Chennai

Date: 19th June 2020

ACKNOWLEDGEMENTS

I am incredibly thankful to Prof. K Giridhar for his constant support and encouragement throughout my project's duration. I feel honored and encouraged to have worked under his guidance. I want to thank him for allowing me to work with him for his patient guidance, and for allowing me to coordinate and conduct research with his research group.
I would also like to take this opportunity to express my profound gratitude to all professors of the Electrical Engineering Department who have imparted knowledge and have motivated me to learn the intricacies of the subjects.
Special thanks to Mr. Krishan Madan for his steady support and guidance. I would like to thank my friends and labmates Shashwat, Dibyajyoti, Nitin ,Pranjali ,Rajasree and some others about whom I have not mentioned here for their help and encouragement.
I want to take this opportunity to thank my parents for their support and encouragement, without which learning in and becoming a part of such a prestigious institution would not have been possible. I would like to dedicate this work to them.

ABSTRACT

Reliable and Covert Satellite (RCS) Communication System is a fully indigenous custom air-interface for providing point to multipoint voice and text links. This system's primary goal is to provide: (i) reliable communications along with (ii) a low probability of detection and interception (LPD/LPI). Here, up to 32 user terminals (UTs) can be attached to a ground-station (Hub) via a geo-stationary satellite. The system can support users spread over vast geographical areas (say, over the entire peninsular region of India).

This thesis presents the design of the reverse link, where the waveform of choice is a novel Spread and Interleaved OFDMA (S-IOFDMA) technique. A 36MHz transponder is shared between the forward link and the reverse link, each using about 17.875MHz in a FDD configuration. While a companion thesis (by Lt. Cmdr. Nitin Chauhan) describes the forward link, this thesis concerns the reverse link design and performance. To provide covertness to the system, the pre-processing SNR observed at the intended receiver (and hence, in at eavesdropper) is very low, and nearly 15dB below the thermal noise floor. Direct sequence type spreading, narrow banding, information repetition, and novel block FEC are employed in tandem to give a total post-processing gain of nearly of 39.12dB. This ensures tremendous reliability and a healthy fade-margin (excess link margin) of more than 18dB, which provides >99 % uptime even in the presence of Rician fading.

The other major challenge of the project is to design the waveforms in such a way that PAPR is low not only at the UT output, but will be low at the satellite output end (after amplify and forward). Based on the number of users active in the system at any given point of time, a lookup table is designed to ensure consistent low PAPR for the pilot signals. Comb selection and choice of spread sequence also played a significant role in keeping PAPR low. Finally, DQPSK is used instead of QPSK to avoid phase error caused due to residual frequency offset. System-level simulation for the above reverse link is performed to capture the reliable un-coded and coded error-rate performance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

CCE	Common channel estimation
CDMA	Code Division Multiple Access
CFR	Channel frequency response
CRC	Cyclic Redundancy Check
Cp	Cyclic prefix
CSI	Cyclic State information
DQPSK	Differential Quadrature Phase Shift Keying
FFT	Fast Fourier transform
IBI	Interblock interference
IFFT	Inverse fast Fourier transform
ISI	Inter symbol interference
MA	Multiple Access
NF	Noise floor
PAPR	Peak power to average power ratio
PRACH	Physical Random Access Channel
QPSK	Quadrature Phase Shift Keying
RCS	Reliable Covert Satellite Communication
SI-OFDM	spread interleaved orthogonal frequency-division multiplexing
SNR	signal to noise ratio
UE	User end
ZC	Zadeoff-chu
ZFE	Zero Forcing Equalizer

NOTATION

θ Angle

CHAPTER 1

Introduction

The objective of this project is to design waveform while accounting for various power constraints in the reverse link (multi-point to point) using a communication satellite's transponder. The primary goal of this communication link is to provide reliability with a low probability of detection and interception (LPD/LPI). The system can support users spread over vast geographical areas. The reverse link handles Communication between various User terminals to Hub through orthogonal multiple access channel using the spread and Interleaved OFDMA(S-IOFDMA) technique. Most transponders operate on a bent pipe principle, transmitting back to Earth with only amplification and shift from downlink to Uplink frequency and vice versa.

Data signals are being spread by spreading sequence to keep it below noise floor (NF), which provides covertness to the system. An intruder can not distinguish whether only noise is present or noise and signal both are present because signal power is below the NF. Due to covertness advantage, SNR is very low in the pre-processing scenario without compromising the signal quality. Due to the Spreading gain, repetition gain, FEC gain, and Narrow-banding Gain, the SNR boost during post-processing at receiver and reliability is ensured.

The system requires four kbps data per user to Hub, and the same requirement holds vice-versa.. The number of users simultaneously supported by the system is 32. This work involves the design of the reverse link of Reliable Covert Satellite Communication system. The design of reverse link supports Communication from a User terminal to Hub uses spread Interleaved OFDMA technique for orthogonal multiple access.

RCS requires the Hub and User device to operate over two different carrier frequencies. As shown in figure 1.3 f1 and f1' being carrier frequency separated by 18 MHz and f2 and f2' is another set of carrier frequency separated by 18 MHz. The channel bandwidth for f1 and f1' will be 17.875 MHz each separated by a 250 kHz guard band, similarly for f2 and f2' .f1 and f2' are used for reverse link, users are transmitting over f1, and Hub is using f2' similarly f2 and f1'are used for the forward link.

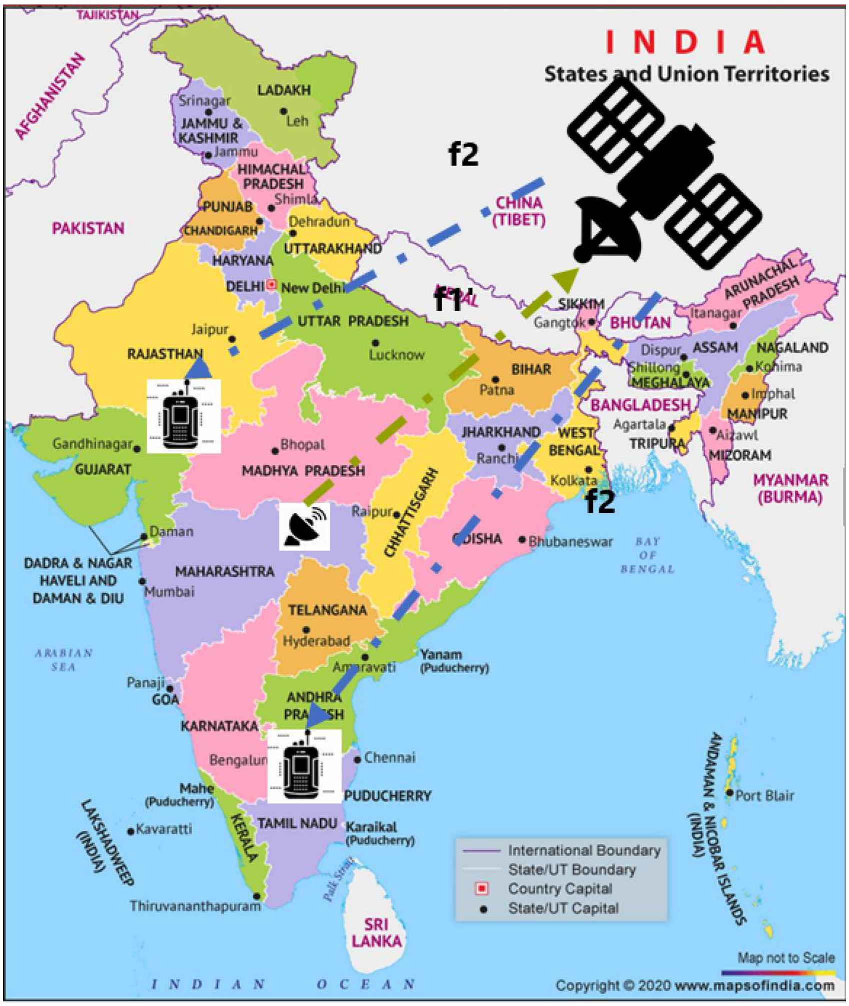

Figure 1.1: Forward Link of reliable Covert Satellite Communication

1.1 Thesis Structure

1. In Chapter 2, we specify the comparison among the Waveform available for Reverse Link.

2. In Chapter 3, we have explain the transmitter block of RCS's reverse link.

3. In Chapter 4, we have discuss the Frame structure block of RCS's reverse link.

4. In Chapter, we have describe the receiver block of RCS's reverse link.

5. Conclusion of the thesis.

6. Future work.

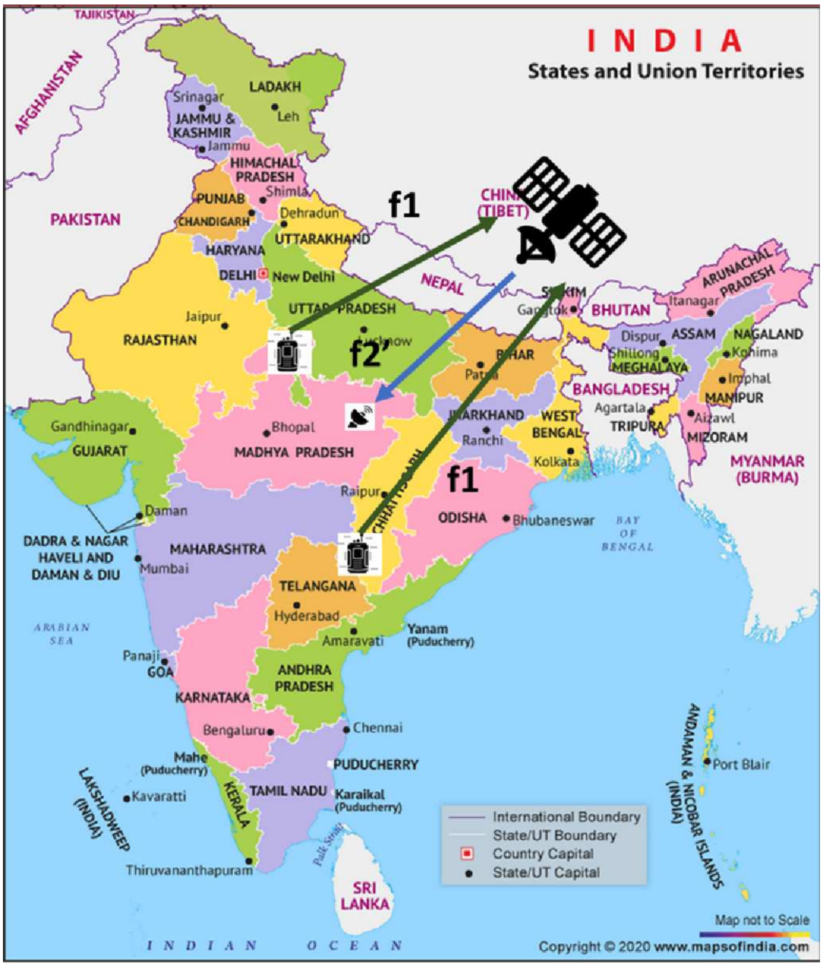

Figure 1.2: Reverse Link of reliable Covert Satellite Communication layout

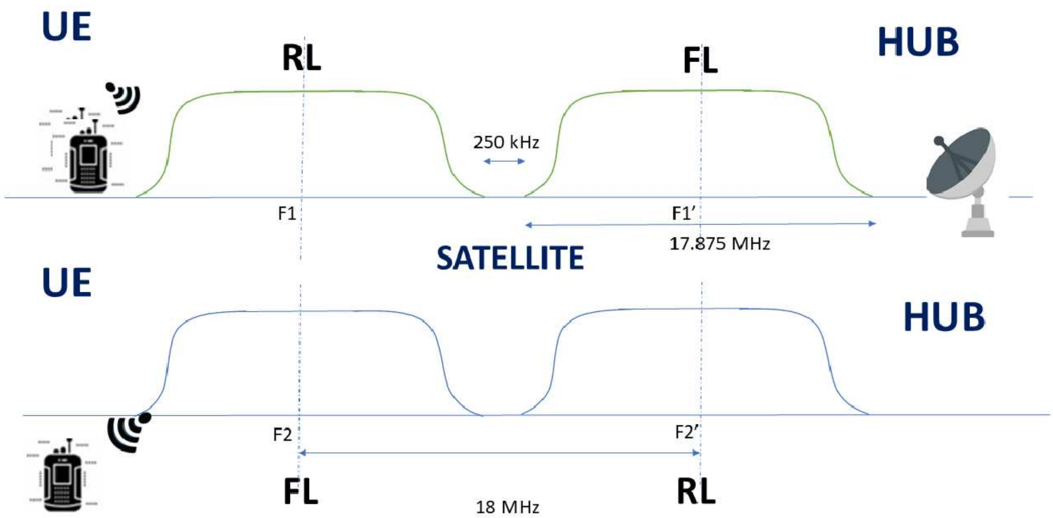

Figure 1.3: Reliable Covert Satellite Communication layout

Multiple access	SI-OFDMA
Transponder Signal bandwidth available	18 MHz
Frame duration	1000 ms
Useful Symbol duration	131.072 μ s)
Chip duration(Tc)	64 ns (0.064 μ s)
Cyclic prefix (Tcp)	8192 ns (8.192 μ s)
Excess Bandwidth factor for RC pulse-shaping	0.144
Occupied Bandwidth ((1+ β) / Tc)	17.875 MHz
Modulation	QPSK / 4-QAM
FEC	Matrix Parity with CRC, Rate 80/108
Bit Rate	4 kbps (per user)
No of user being supported simultaneously	32
Spreading factor	64
Repetition factor	2
frequency of operation	Ku-band (10 GHz to 14 GHz)

Table 1.1: The reverse link design Specifications

CHAPTER 2

Waveform choice for Reverse Link

2.1 OFDMA

OFDMA is a MA technique which can assign a different number of subcarriers to individual users. It transmits the data over many orthogonal narrowband subcarriers instead of transmitting the signal over the entire bandwidth. It permits simultaneous transmission from multiple users. The orthogonality of different users' signals is maintained even for transmission over time-dispersive channels. In OFDMA, inter-symbol interference (ISI) can be avoided by using Cyclic prefix. OFDMA gives low computational complexity due to its implementation using Fast Fourier Transform (FFT) algorithm. However,multicarrier-based MA schemes like OFDMA suffers from high peak to average ratio. Thus, power amplifiers with a large dynamic range are required. It is required that the mobiles use as little battery power as possible. We can not use heavy power amplifers at UE but clearly power is not an issue at base stations. ODFMA is not a good choice for UE to hub link

2.2 Block modulated CDMA

In forward Link, Block modulated CDMA is used as a wave form but we can not the use same Block modulated CDMA wave form for reverse link due to the following reasons

1. As every user's data passes through an FIR channel, orthogonality across users will be lost at receiver.
2. To resolve orthogonality among users,Hub has to compensate for all the channels which is not feasible.

2.3 SI-OFDMA

I-OFDMA can be derived from a single carrier based MA like DS-CDMA perspective by using frequency-domain orthogonal signature sequences (FDOSS) as well as, it can be obtained from a multicarrier-based MA scheme like OFDMA by the introduction of an interleaved subcarrier allocation

. I-OFDMA combines many advantages of single and multicarrier-based MA schemes. i)It produces a multi-carrier signal at the receiver, which provides orthogonality in the frequency domain. ii)As a single-carrier scheme, each user has a very low transmit PAPR signal compare to PAPR of multi-carrier. It provides benefits like the low complexity, especially at the transmitter side, which is lower than the transmitter of OFDMA, the low PAPR of the transmit signal, and the excellent power efficiency. I-OFDMA scheme has advantages of CDMA as well as OFDMA. Due to CDMA like properties, it has low complexity for signal generation, low PAPR, and high-frequency diversity. Due to OFDMA type properties, it has low complexity for user separation and low computational complexity for equalization.

I-ODFMA provides PAPR similar to the CDMA. I-ODFMA is an excellent choice for the reverse link because high PAPR is a critical issue at the satellite end. To fulfill the requirement of covertness and to meet Low probability of detection or low probability of interception signal should be spread with spreading sequence. Spreading the data with spreading sequence and implement it on the I-OFDMA, so the name of the waveform is I-OFDMA

2.3.1 Frame Structure

In the reverse link design, every UE will transmit 2,704 different QPSK symbols (16 subframes $\times$ 169 complex data symbols) repeating twice which allows for 3 dB gain.

In the frame structure design, the chip duration is 0.064 μs, and the total number of chips is 1,56,25,000. The PRACH structure has 14,95,848 chips, which corresponds to 95.734 ms. PRACH design is planned with a pool of ZC sequences where a new UE joining network will transmit one of the sequences with 4096 chips as a PRACH signal for ranging.

Periodic ranging has 4096 chips duration of the Zadeoff-chu sequence repeated twice for each UE.This ensures that all the UEs have been ranged such a way that relative delay between first and last arriving uplink signal is less than cyclic prefix.

Each frame consists of 16 subframes(1,38,67,008chips and 888ms duration), and each subframe has 8,66,688 chips and duration of 55.5 ms . Every subframe has one Common Channel Estimation (CCE) and 169 different SI-OFDMA symbols carrying User data. In every frame, SI-OFDM symbols repeated twice, making the total number of SI-OFDM symbols 338. Each SI-OFDMA symbol consists of 2176 (2048 Data+128 CP) chips.

CCE will have 1,31,200 chips. CCE consists of a pilot SI-OFDMA symbol from each UE, which was repeated 64 times for an 18dB boost in SNR for high-quality channel estimation.

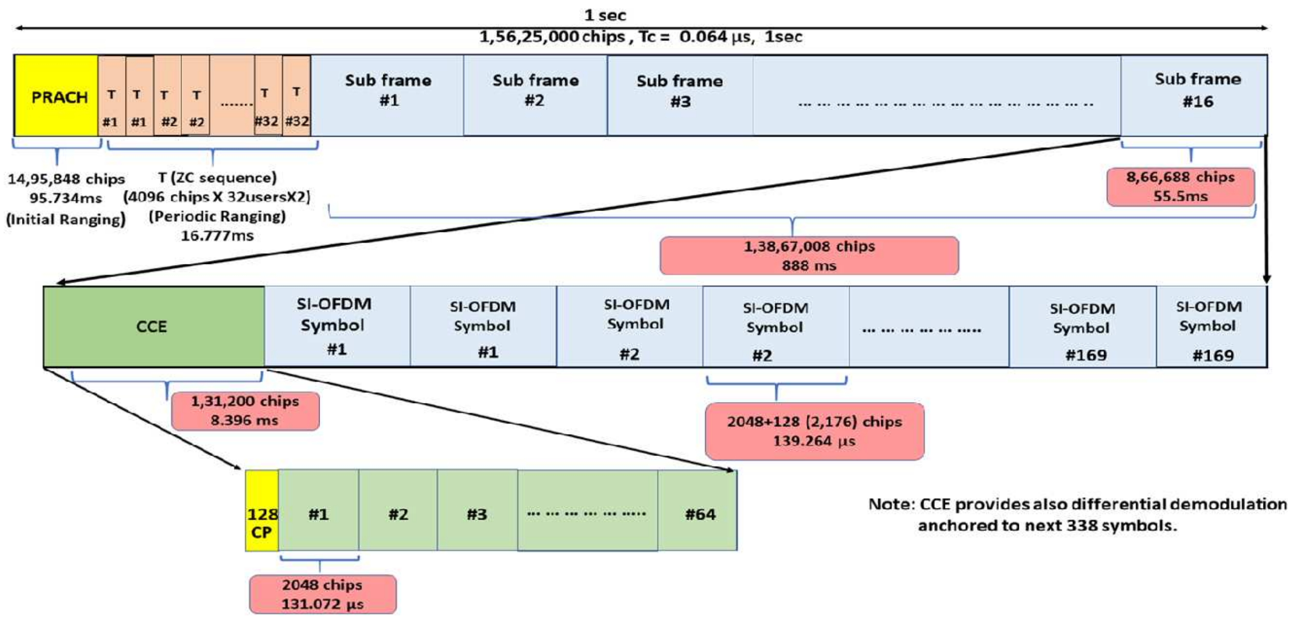

Figure 2.1: RCS Reverse link-Frame structure

CHAPTER 3

Transmitter Block

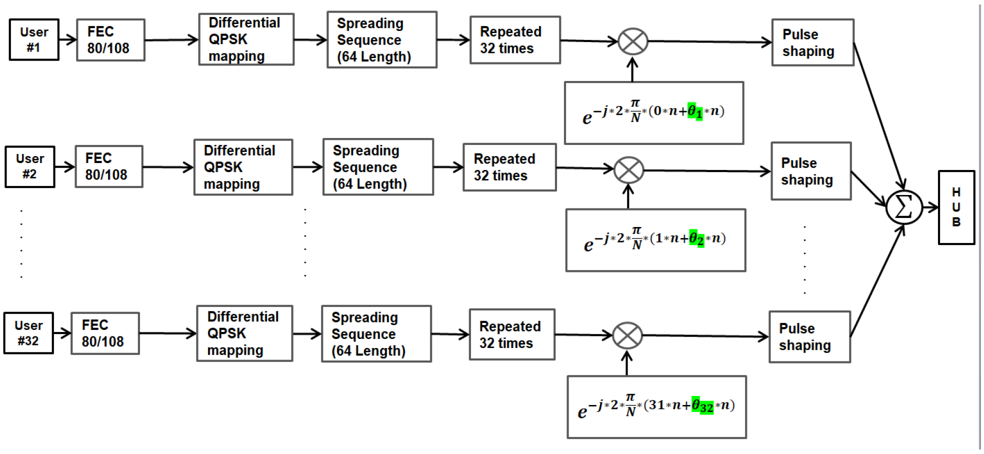

Figure 3.1: RCS Reverse link - Transmitter

3.1 FEC using CRC and MPCC

The reverse link works on spread interleaved OFDMA(SI-OFDMA).Each user's data from UE is encoded by the Forward error correction block (80/108 coding rate) to achieve an additional 2 dB to 3 dB coding gain.

This FEC scheme used CRC and two-dimensional parity-check codes (Matrix Parity Check Code (MPCC)) for the error control. The technique is able to detect and correct all one and two-bit errors in a given code block. First data bits are encapsulated with CRC and after that the matrix formed is used to compute 2-D parity codes.

The decoder has two sections, first is the error detection and evaluation of error correction possibility, second is Error correction. The hard decision decoder significantly reduces the computational load and decoder power requirement.

3.1.1 Encoder

The CRC polynomial selection is a critical part of the syndrome generation and error detection. Calculate CRC for each user's N bits stream then reshape vector into M time N matrix(M=11 and N=8). Compute row and column parity for data pits, including CRC bits.

3.1.2 Decoder

For decoding, a lookup table saves syndromes for all single-bit errors. Two-bit error (few typical combinations for three-bit error) corrections are possible for hard decision decoder implementation. Calculate CRC syndrome for the received bitstream, excluding parity and CRC bits, then evaluate Row and Column parity bits for received bits, including CRC bits. In case errors are more than two bits,block decoding will failed. Single-bit error correction are performed when row and column parity check indicate single bit error, and the syndrome matches the reference syndrome value from the lookup table. This reference syndrome is gathered from the location pointed by parity check results. Seven different types of two-bit errors can occur in the received data. Each class is specified by the row and column parity check results. For every kind of two-bit error, the parity check result gives a small set of possible error locations

3.2 Modulation

The reverse link works on spread-interleaved OFDMA(SI-OFDMA) with differential QPSK modulation, which supports a data rate of 4 kbps for each user. The FEC encoded data stream is mapped to differential modulated QPSK symbols. In Differential quadrature phase-shift-keying (DQPSK), the information is conveyed by the absolute phase difference of each symbol with previous symbol. In DQPSK, the information sent by establishing a particular phase of one symbol relative to the previous symbol. DQPSK provides a promising alternative as it, like QPSK, transmits 2 bits per symbol. Hence, the symbol rate is half the bit rate. DQPSK is used instead of QPSK to avoid phase error caused by residual frequency offset.

3.3 Spreading sequence

Data symbols are spread by spreading sequences of length 64 to provide covertness in RCS. Walsh code, Zadoff-chu sequence, and others are available options. Why did we choose Zadoff-chu as a spreading sequence? When Walsh code is used as a spreading sequence, energy is concentrated at a single sub-carrier for all the users. If deep fade occurs at that subcarrier, Signal will be lost because all the energy is confined at a single subcarrier. If Zadoff-chu used as a spreading sequence, the energy spreads among the 64 available sub-carriers. As shown in Figures 3.2 and 3.3. The basic form of the Zadoff-chu sequence can be created by the formula as shown below

$$z_{seq} = exp(-1i * pi * u * n. * (n + cf + 2 * q)/Nzc)$$

Where

$$q = 0, n = 0 : N_{\text{ZC}} - 1,$$

$$0 < u < N_{\text{ZC}}\ and\ \text{gcd}(N_{\text{ZC}}, u) = 1,$$

$$cf = mod(Nzc, 2),$$

$$N_{\text{ZC}} = \text{length of sequence.}$$

The data symbol stream first is spread by the Zadoff-Chu by a length 64 ZC spreading sequence. Spreading of data symbols is needed to provide low signal power because the RCS system works on low signal power, which is below the noise floor to provide covertness of the system. We spread each user data symbol by best chosen Zadoff-chu spreading sequence to give an overall low PAPR signal at the Satellite end. Individual PAPR of each user is close to unity, but when they are combined at the satellite end, PAPR increases drastically. If we use different Zadoff-Chu spreading sequences for every user, The system will get higher PAPR results as compare to using single Zadeoff-chu for every user. Unlike the Forward link, the Reverse link uses spreading sequences to provide covertness to the system, not orthogonality. As a result, we can use a single Zadoff-Chu sequence as a spreading sequence for every user.

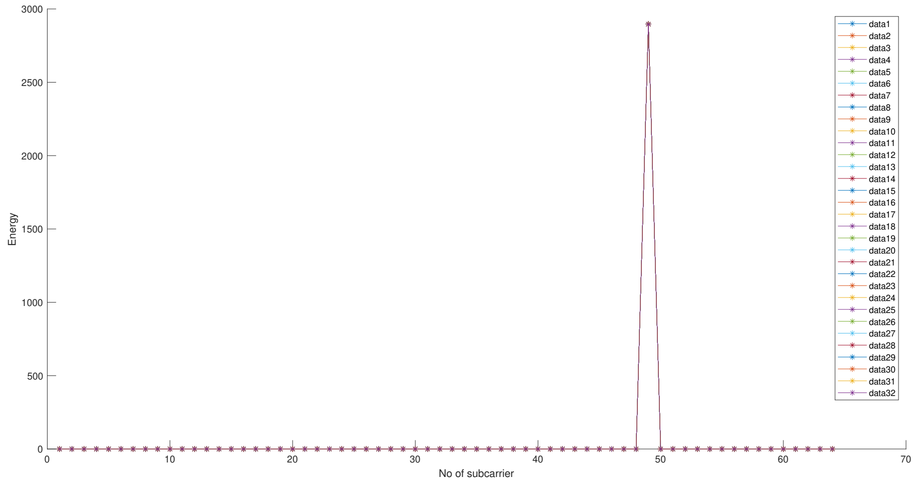

Figure 3.2: Energy diagram (Spreading sequence = Walsh code)

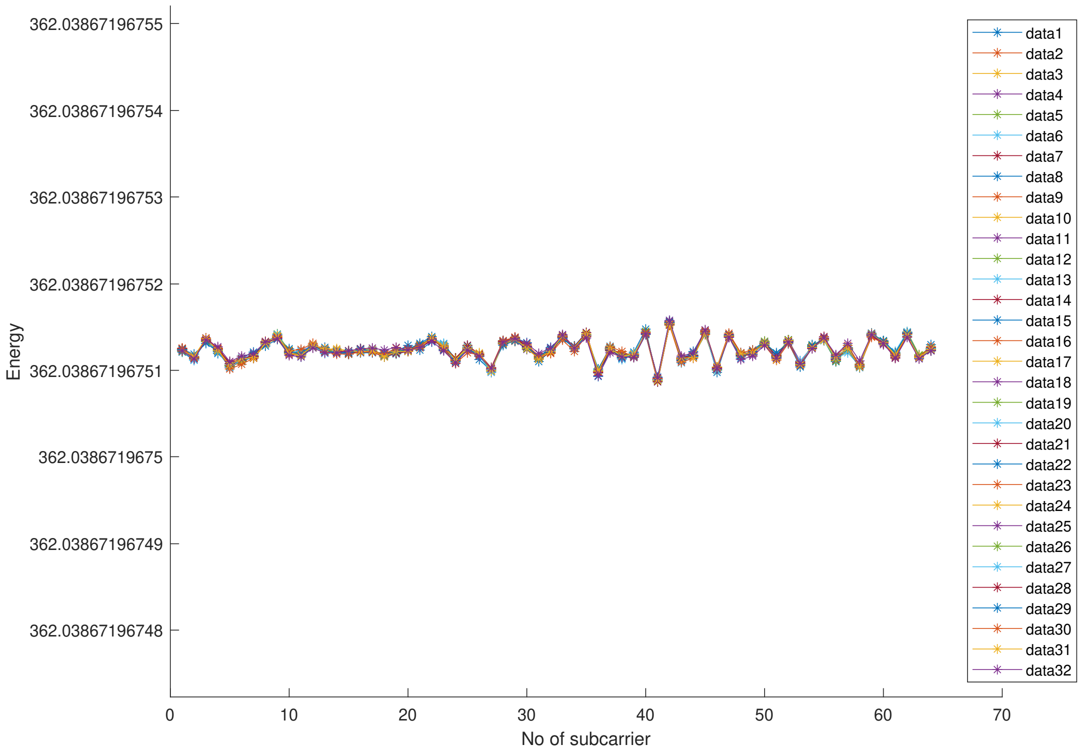

Figure 3.3: Energy diagram (spreading sequence= Zadeoff-chu code)

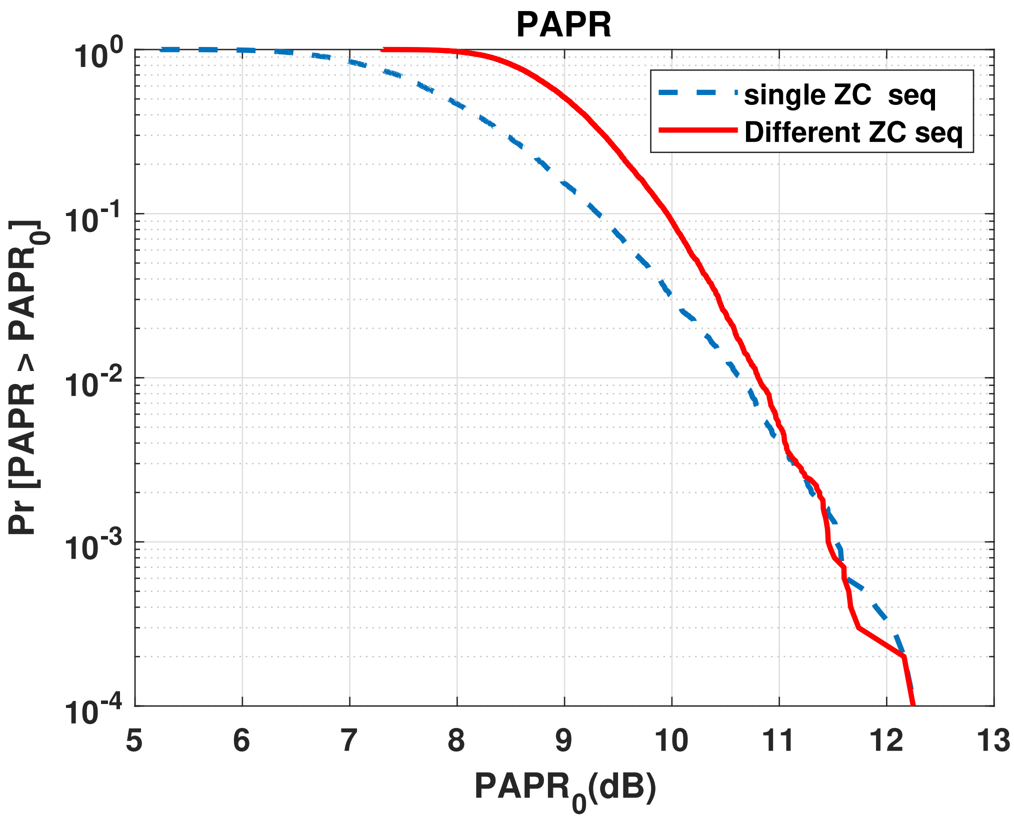

Figure 3.4: PAPR comparison between spread with different ZC sequence for each user and same ZC sequence for each user

3.4 Comb selection

Each user's data block is repeated 32 times to accommodate 32 users, followed by appropriate comb allocation at every user terminal. Allocating comb to each user is done by multiplying e^{j*k*n} where k is the comb location of users. Comb allocation in the time domain leads to a shift to the user data in the frequency domain, which makes all users orthogonal to each other. Appropriate comb location pattern is all users must be equidistance from each other to get the best PAPR result

1. Comb index (K) varying from 0 to user-1 in our case max no user which can be supported by the system is 32 (if users are integer multiple of 2)
   n is varying from 0 to n-1
2. K=(user/32)*n
   Example =>if users=4 best possible comb index are 0 ,8 ,16 and 24 .
   if users=8 best possible comb index are 0 ,4 ,8 ,12 ,16 ,20 ,24 and 28
3. (if users are odd)
   Example => if user=5 best possible comb index are 0 ,8 ,16 , 24 and 4
   if users=9 best possible comb index are 0 ,4 ,8 ,12 ,16 ,20 ,24 ,28 and 2

In case all 32 users are present, we don't have any choice to get low PAPR by using the appropriate comb selection method because it doesn't matter in which order we choose the comb but distance between comb matter. The system is not fully loaded then make comb selection like every user's data must be equidistance to each other.

3.5 Compensation frequency offset

In reverse link, every chip (data, pilot) transmitted by UE must be sent after frequency compensation (shown as for every user) represented by $e^{j\theta}$ in fig, which is estimated through the forward link. Unlike the forward link, the reverse link scenario is multipoint to point where multiple UEs transmit at the same time, and each user's data has a different frequency offset error, which is difficult to handle at hub's side. To avoid intersymbol interference (ISI) through the insertion of a cyclic prefix (CP) at the transmitter and its removal at the receiver. Pulse shaped (Raised cosine window) SI-OFDMA is used as per the framing structure, then converted to analog form, mapped onto the carrier, and transmitted.

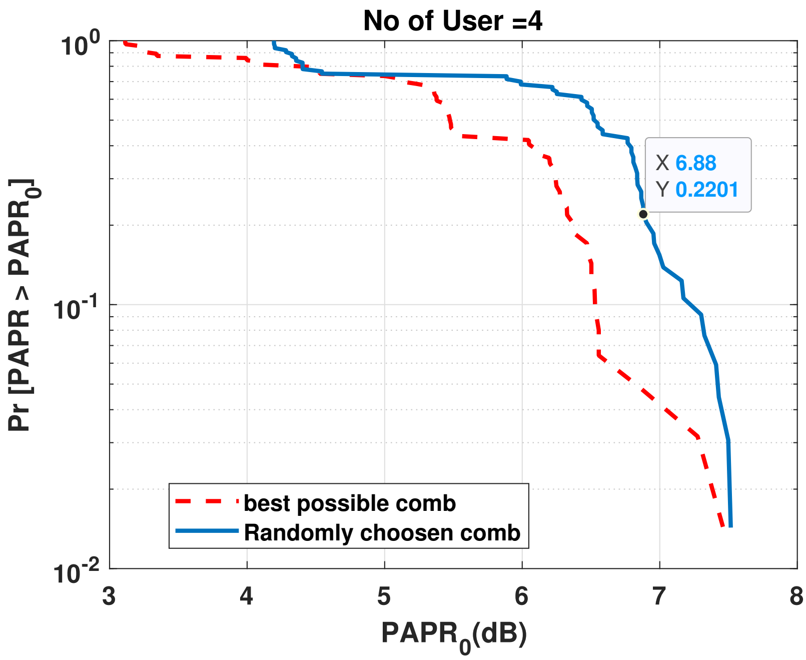

Figure 3.5: Comparison between patterned comb selection vs random comb selection when no of users =4

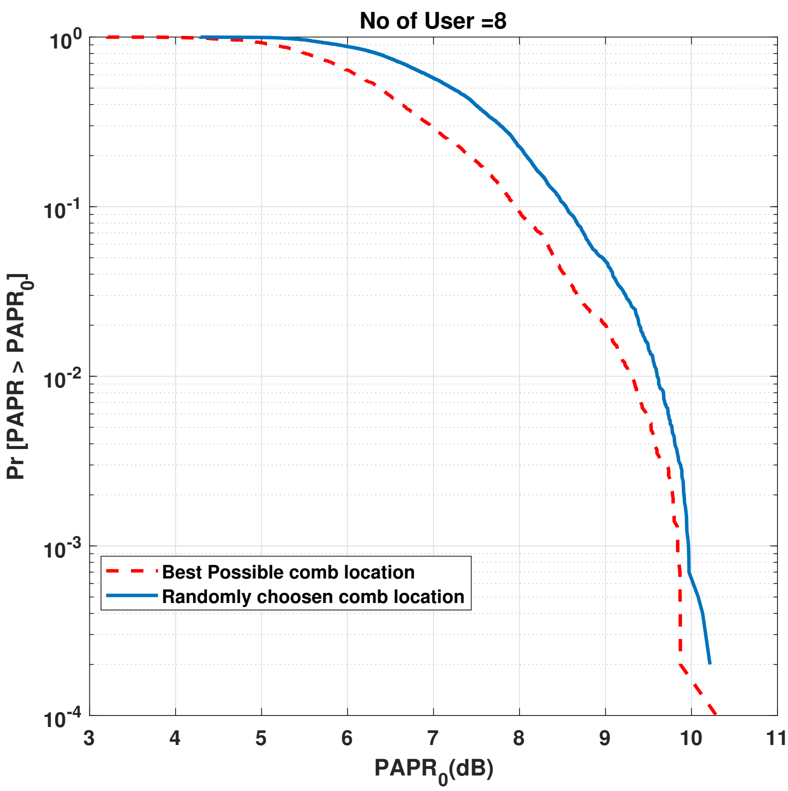

Figure 3.6: Comparison between patterned comb selection vs random comb selection when no of users =8

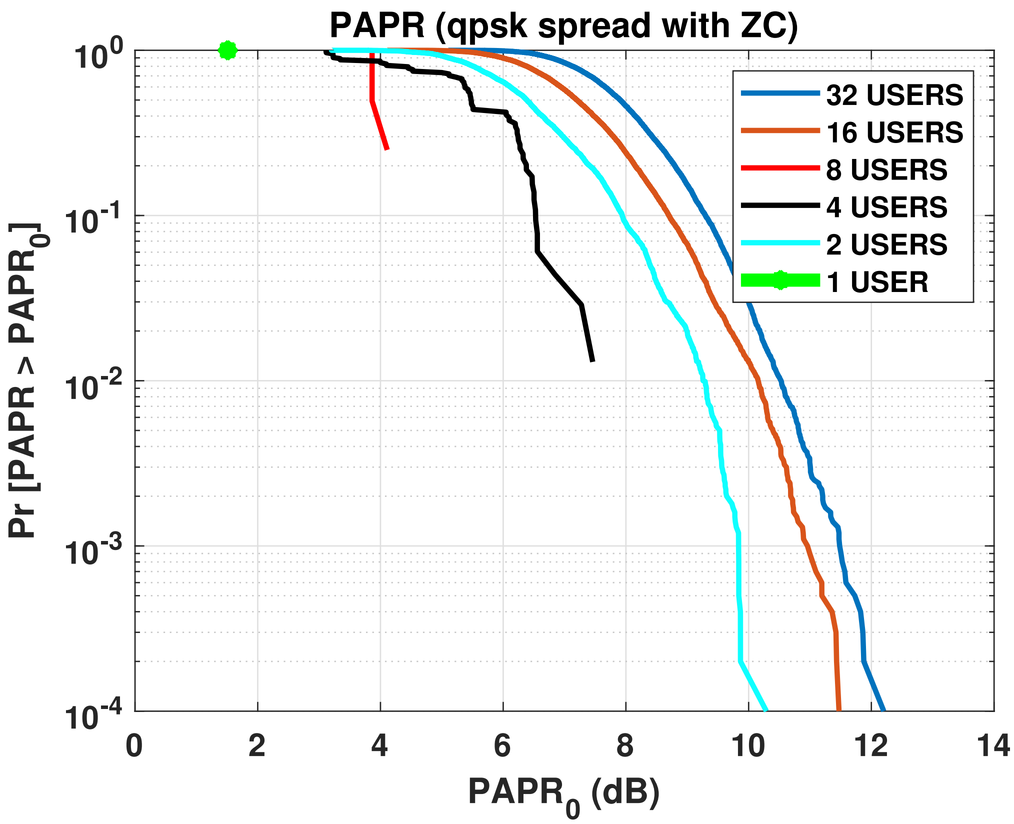

Figure 3.7: PAPR at Satellite end

3.6 Pilot symbols at Transmitter end

When transmitted signal are sent through a channel, the channel impairments usually corrupt the received signal, and we get corrupted signal at the receiver end. The channel should be estimated and compensated in the receiver to recover transmitted bits.The channel can be estimated by using pilot symbols known to both transmitter and receiver.

Users are orthogonal to each other. The orthogonality allows each user's received signal has expressed as the product of the transmitted signal and channel frequency response. The transmitted signal recovered by estimating the channel response of an individual user. Pilot signals are different for the different number of users. The pilot signal must be chosen according the number of users. A question arises of what the best pilot signal combination is. If we randomly select same QPSK symbol as a pilot signal combination for different users, then PAPR can be as high as 15dB.

To avoid high PAPR, choose a pilot signal according to the number of users. The pilot combination is best for 32 users; it won't be suitable for any other users combina-

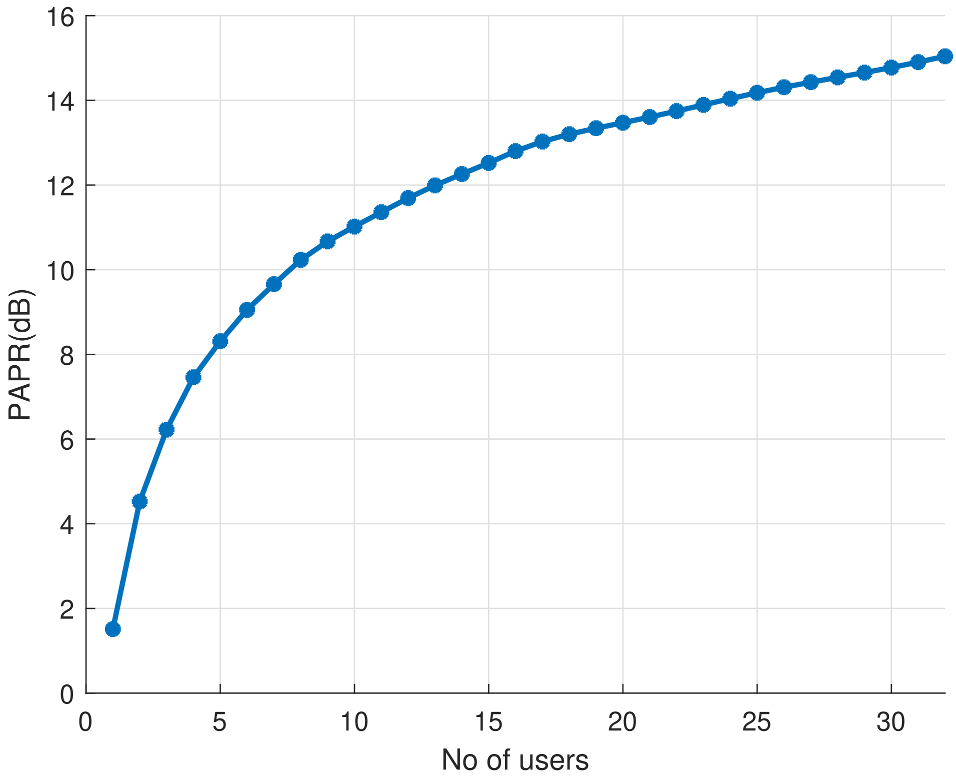

Figure 3.8: Using random same sequence as a pilot symbol

tion.As shown in Figure 3.9, using the best combination of pilot symbols for 32 users is not performing well when total no users are 11.similarly while using the best combination of pilot symbols for 32 users is not performing well when total no users are 7. The pilot signal has designed according to the number of users present in the system. For example, if the number is users are 30, then pilot signals will be different, and if the number is users are 12, then pilot signals will be something else. By following this method, PAPR came down up to 8.85 dB. In order to optimize the PAPR at the satellite end, the pilot design has been customized based on the number of UEs in the network. A lookup table has been formed, which helps a UE choose pilot QPSK symbols depending on the number of UEs already connected to it. This scheme will ensure the overall PAPR in all the cases where the number of UEs varying until 32 has been kept under 8.85 dB, which leaves us room for 2-3 dB boosting CCE at UE end.

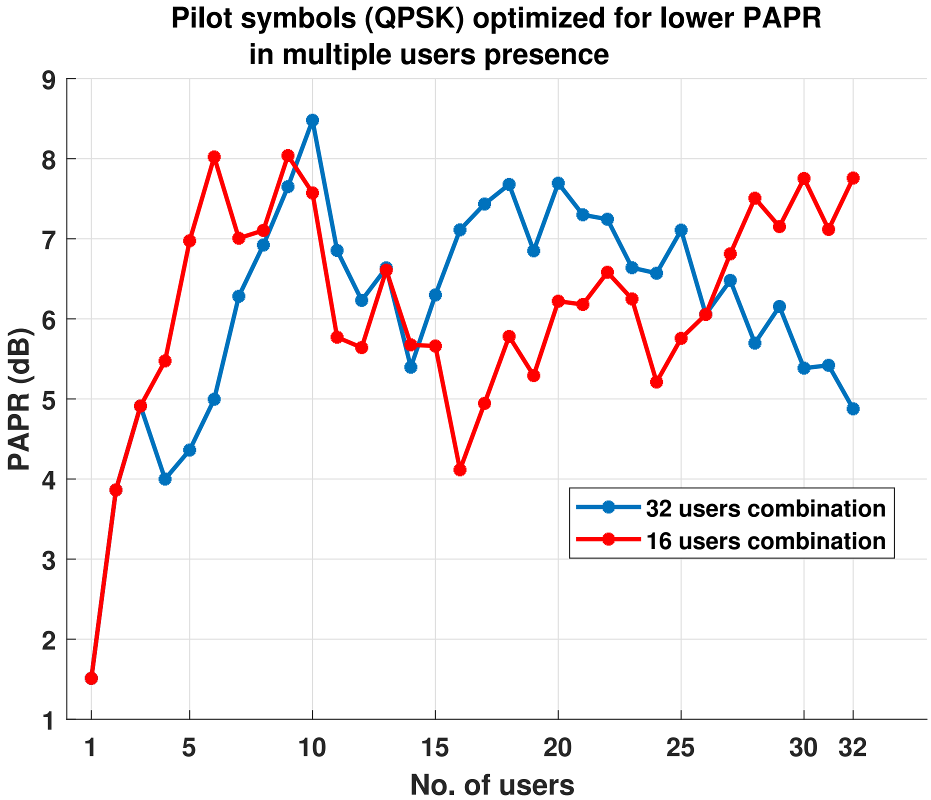

Figure 3.9: Using best chosen symbols combination for 32 or 16 users as a pilot symbols

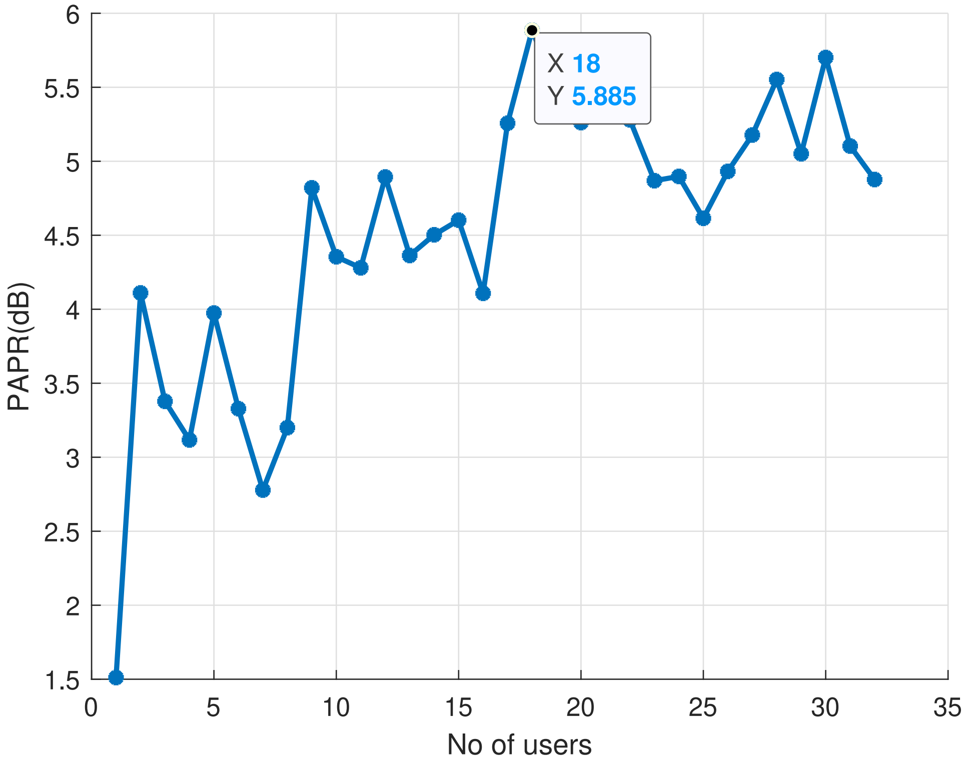

Figure 3.10: Using best chosen symbols as a pilot symbols for every user

CHAPTER 4

Receiver Block

4.1 Timing synchronization

Timing synchronization is a necessity for any wireless communication system to work correctly. In Timing synchronization, the receiver node determines the correct instants incoming signals sample. Timing synchronization involves cross-correlation with all the assigned Zadoff-Chu sequences for existing UEs in the network. Cross-correlation ensures that all the UEs have ranged in such a way that relative delay between first and last arriving uplink signal is less than cyclic prefix. If the channel delay spread is shorter than the duration of the CP, no ISI occurs. According to the first and last peak from the cross-correlation of Zadoff-Chu (ZC), we can choose IBI to free the FFT window.
The cyclic prefix (CP) is an identical copy of some portion from the end of the symbol. The cyclic prefix used to eliminate intersymbol interference(ISI) from the previous symbol. The insertion of a cyclic prefix (CP) occurs at the transmitter and its removal at the receiver.

4.2 Channel estimation

In general, the channel estimation can be done by using a preamble or pilot symbols known to both transmitter and receiver. The transmitted signal recovered by estimating the channel response. Channel state information (CSI) is obtained by adding pilot symbols at the start of each subframe symbol.
In every start of a subframe, channel frequency response (CFR) estimation for every UE to Hub link has done first by coherently adding 64 copies of received pilot symbols to boost SNR by 18 dB and followed by FFT. Then, each UE's received comb has been separated and multiplied by conjugate of UE-specific transmitted pilot fetch us CFR of each UE. This estimated CFR also captures the additional phase error caused due to shifting in the FFT window from a critical boundary.

.

4.3 Zero forcing equalization

The technique of equalization to compensate for the effect of the channel, which distorts the transmitted signal. Different kinds of equalizers have used for equalization depending upon the application of the system and upon the type of communication channel.
ZF equalizer is used to compensate for the effect of ISI.ZF is useful in mitigating the ISI effect rather than induced noise in the signal.
As every data symbol has transmitted twice, It will provide extra 3dB gain. After taking FFT, separate each UE specific comb from each replica. Equalize (ZFE) using every UE's respective estimated CFR and then coherently added with each other.

$$\hat{X} = (\hat{H^T})(\hat{H}^T \hat{H}) * Y$$

.

4.4 Zero interleaving

After completing the zero-forcing equalization (ZFE) process for all UEs. Every UE's equalized frequency response is interleaved with 32 zeros. To avoid any frequency shift at the end, after zero interleavings, assign it to 1st user's comb and then take IFFT. This will gives 15 dB gain as every UE occupies a portion of the whole bandwidth.

.

4.5 De-spread and Decoding

Truncate 2048 IFFT output to first 64 chips, and de-spread with transmitted ZC followed by mapping to closest DQPSK symbol. Spreading factor 64 added gain of approx 18.06 dB.Final symbol decisions will be made for individual UE through differential demodulation to previously received symbols.When the signal is passed through a noisy channel, DQPSK modulation is prone to errors while transmitting signals through noisy channels than PSK. BER performance of DQPSK is approximately 3dB worse than QPSK. Final symbol decisions will be made for individual UE through differential demodulation to previously received symbols.

4.6 Post-Processing Gain

To provide the covertness system ensures that signal power will be below NF, but at the same time, we don't want to compromise the quality of the system. Due to the Spreading factor gain, repetition factor gain, FEC gain, and Narrow-banding gain SNR boost by almost 39.12 dB during post-processing at receiver and reliability have ensured.

Simulation Parameter	**Gain**
Spreading gain(64-length)	18.06 dB
Narrow banding-Gain	15.05 dB
FEC	MPCC and CRC 3 dB gain at $10^{(-5)}$ uncoded BER
Repetition Gain	3 dB
total Gain	39.12 dB

Table 4.1: post-processing gain

4.7 Simulation results

System Level simulation parameters (Assumptions)

1. 100 % loaded system (All 32 users are present)
2. No short term fading.
3. No relative power difference among all users while their signal reaching Satellite receiver end.
4. Timing information is assumed to be known.
5. No CFO error.
6. Two times repetition of data symbols is implemented for 3dB boost. No pilot symbol's power boost (both data and pilots are transmitted with equal power).
7. Each user sends 169 QPSK symbols repeated twice and 1000 such Monte Carlo simulations has been performed to calculate average BER of the system for each SNR.

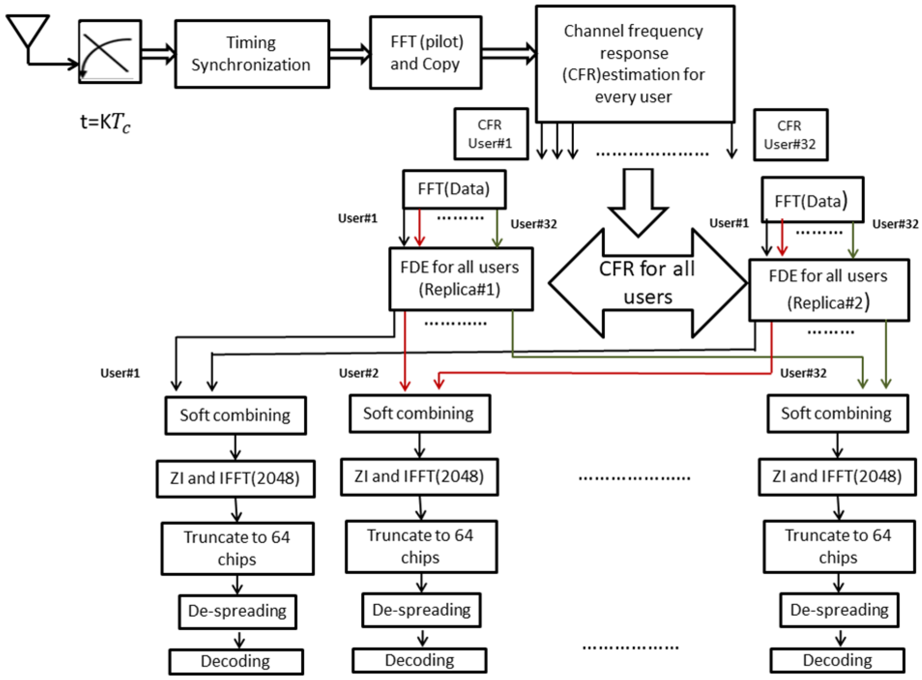

Figure 4.1: RCS Reverse link-Receiver

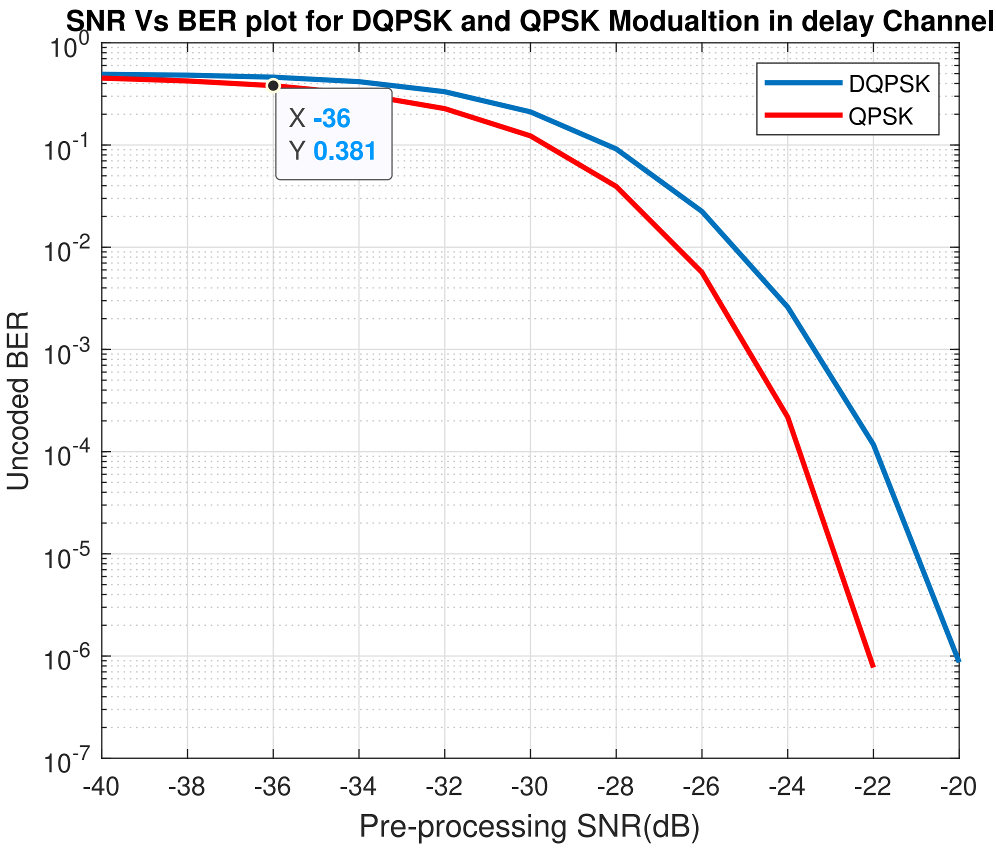

Figure 4.2: Comparison between uncoded BER of QPSK and DQPSK

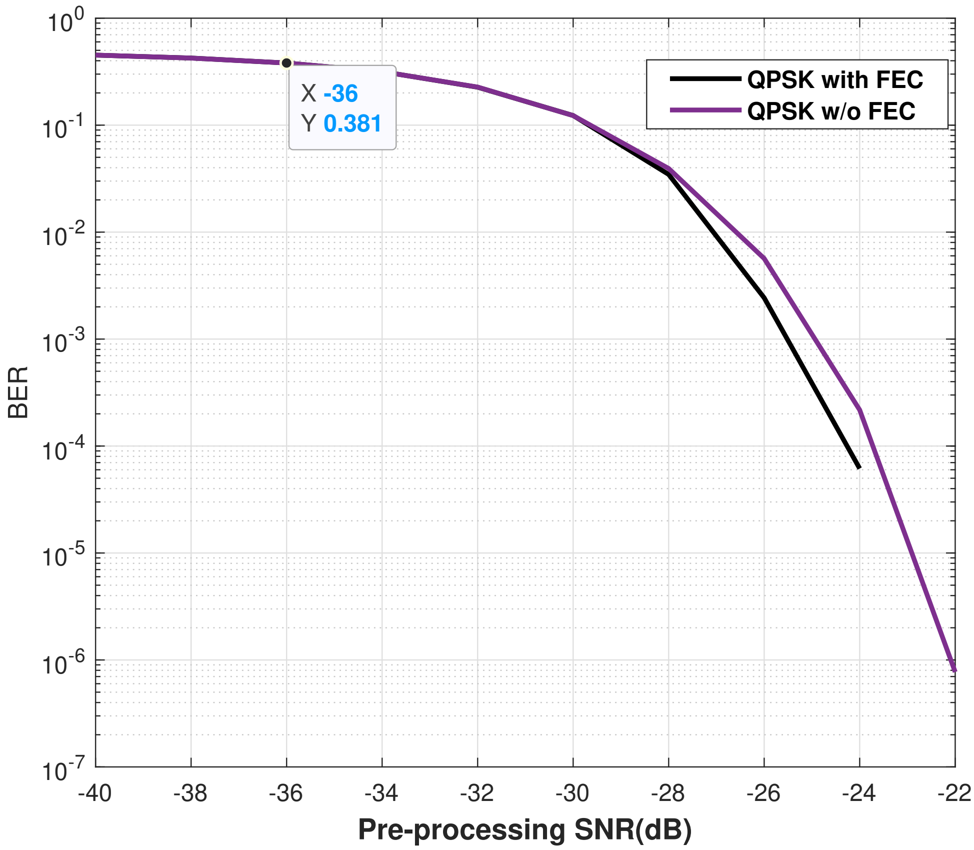

Figure 4.3: Comparison between coded and uncoded BER of QPSK

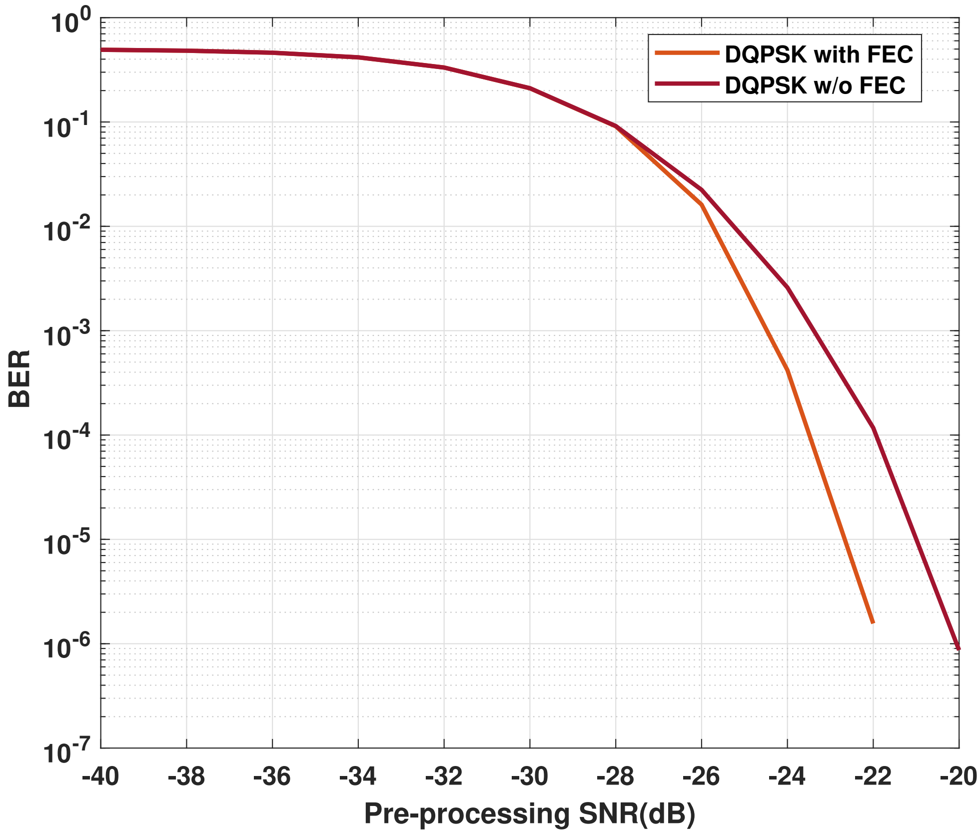

Figure 4.4: Comparison between coded and uncoded BER of DQPSK

CHAPTER 5

Conclusion

- Reverse link or Uplink in this multi-point to point network using satellite as a transponder in amplify and forward mode, achieved the required LPI/LPD goal while supporting an user uplink data-rate of 4 Kbps per user.
- Mindful waveform design allowed to handle multipath and provided extra head-room to accommodate small errors in uplink ranging.
- Efficient pilot design for channel estimation helped us to restrict the PAPR of the multiple access signal received at satellite end approximately below 6dB for a fully-loaded system, where as its absence of may shoot up the same PAPR to 15 dB in the worst case.
- In addition to it, the same PAPR has been controlled with the optimum comb selection (user resource allocation) in the chosen multiple access scheme for the data transmission in the reverse link.

CHAPTER 6

Future Work

The additional system level aspects which needed more attention further is PRACH processing and study the effect of residual CFO error over BER.

Has to finalize the multipath profile for the considered use case and how to incorporate affects of the two satellite links (as amplify and forward being used in between user and hub) on the measurement model.

Addition to this simulation study, a lab scale fool proof demo of the chosen signal processing concepts is being built using Zynq Ultrascale MPSoc and ADRV 9009.

REFERENCES

1. **Chu, D.** (1972). Polyphase codes with good periodic correlation properties (corresp.). *IEEE Transactions on Information Theory*, **18**(4), 531–532.

2. **Frank, T.**, **A. Klein**, and **E. Costa** (2007). Ifdma: A scheme combining the advantages of ofdma and cdma. *IEEE Wireless Communications*, **14**(3), 9–17.

3. **Frank, T.**, **A. Klein**, **E. Costa**, and **E. Schulz**, Ifdma - a promising multiple access scheme for future mobile radio systems. *In 2005 IEEE 16th International Symposium on Personal, Indoor and Mobile Radio Communications*, volume 2. 2005.

4. **M. Madhusoodanan, S.** and **K.Giridhar**, Power efficient flexible fec scheme for 5g iot applications. *In 2016 37th Wireless World Research Forum(WWRF) Meeting*, volume 1. 2016.