Interference Suppression Techniques for Bluetooth and Proposed Bluetooth Evolution Technologies

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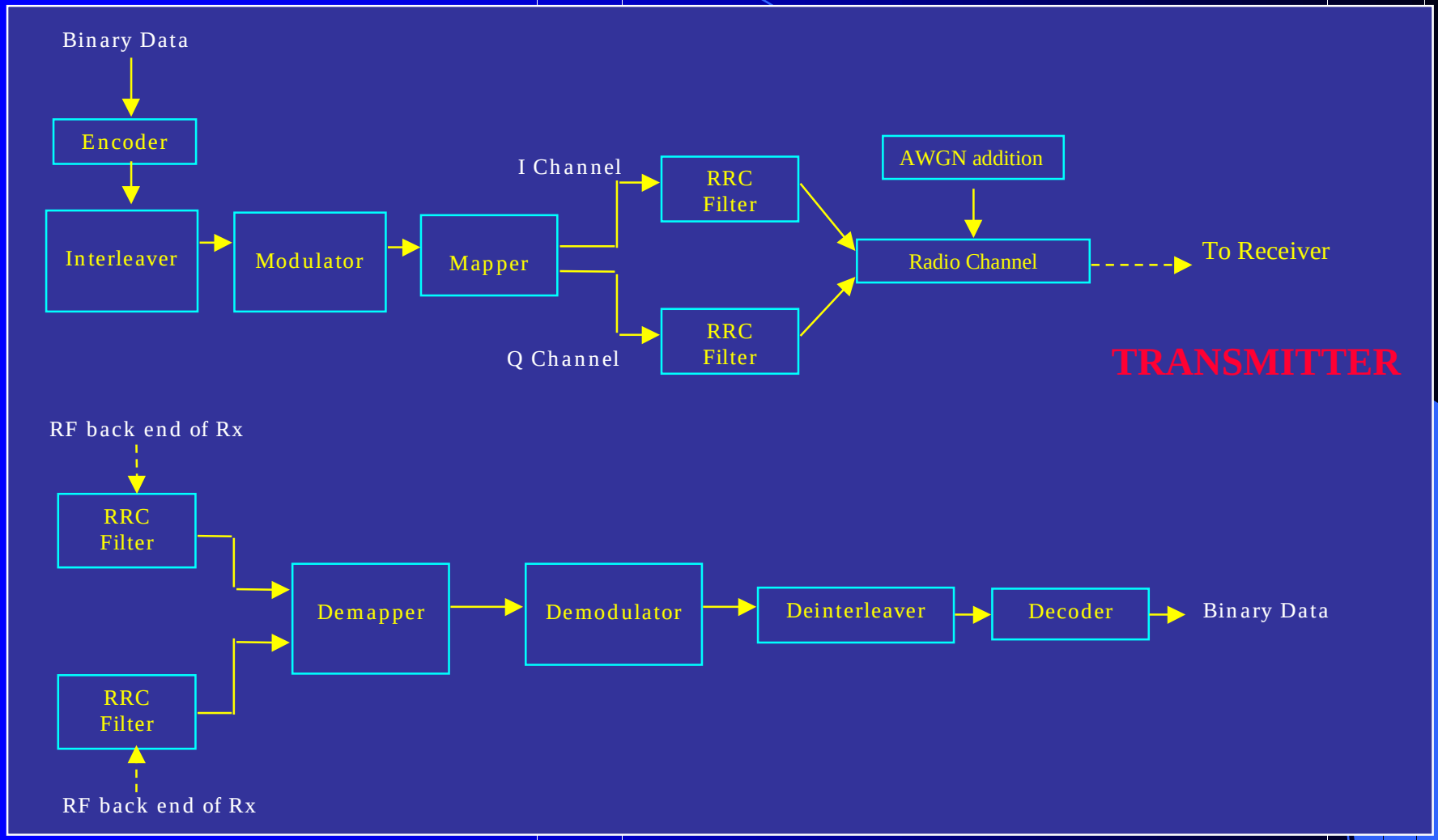
Talk Plan . . .

- Introduction to Bluetooth base band simulation structure
- Summary of investigation on high data rate schemes within a home environment
- Implementation of Frequency Hopping and BD_ADDR
- Results and conclusion of interference due to frequency collision
- Discussion and implementation of spatial interference suppression techniques using the Bluetooth Access Code as a training sequence for an antenna array
- Discussion of the results obtained
- Conclusion and future work

Objectives of Research Work

- Increase data rate capability for time-bounded and non-time bounded applications for multi-storey indoor environment
- Investigate the types of interference that exists within a Bluetooth operating environment
- To study and implement the Frequency Hopping and Bluetooth Addressing schemes in the current Bluetooth standard
- To implement the null steering technique using Least Mean Square (LMS)algorithm for interference suppression
- Feasibility of using the Bluetooth Access Code as a training sequence for spatial interference suppression

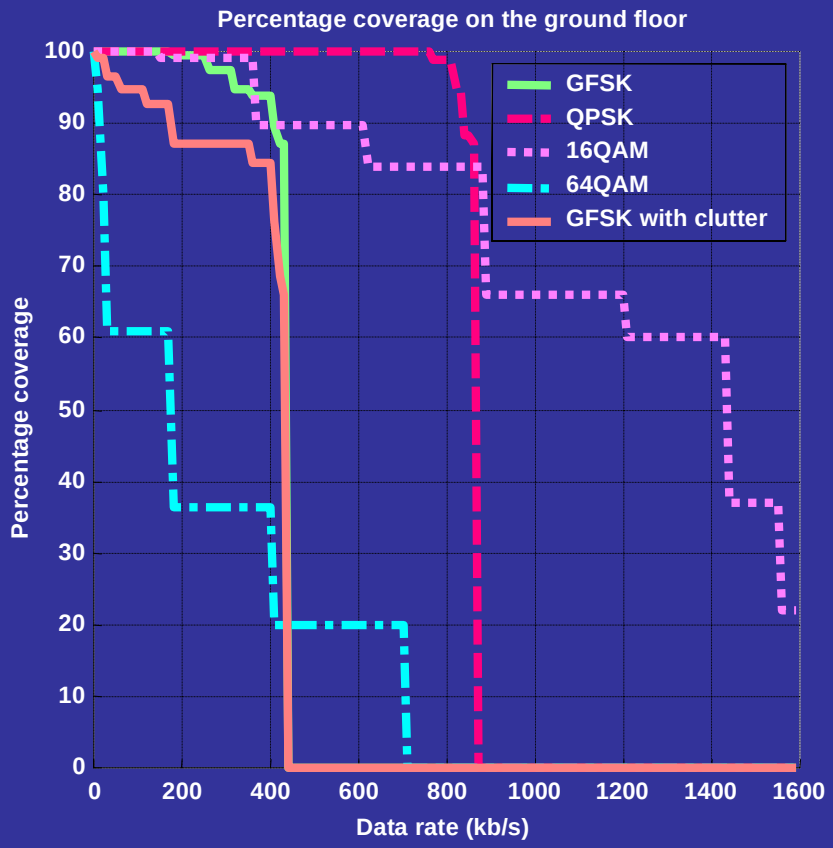
Software Simulation of Baseband Structure



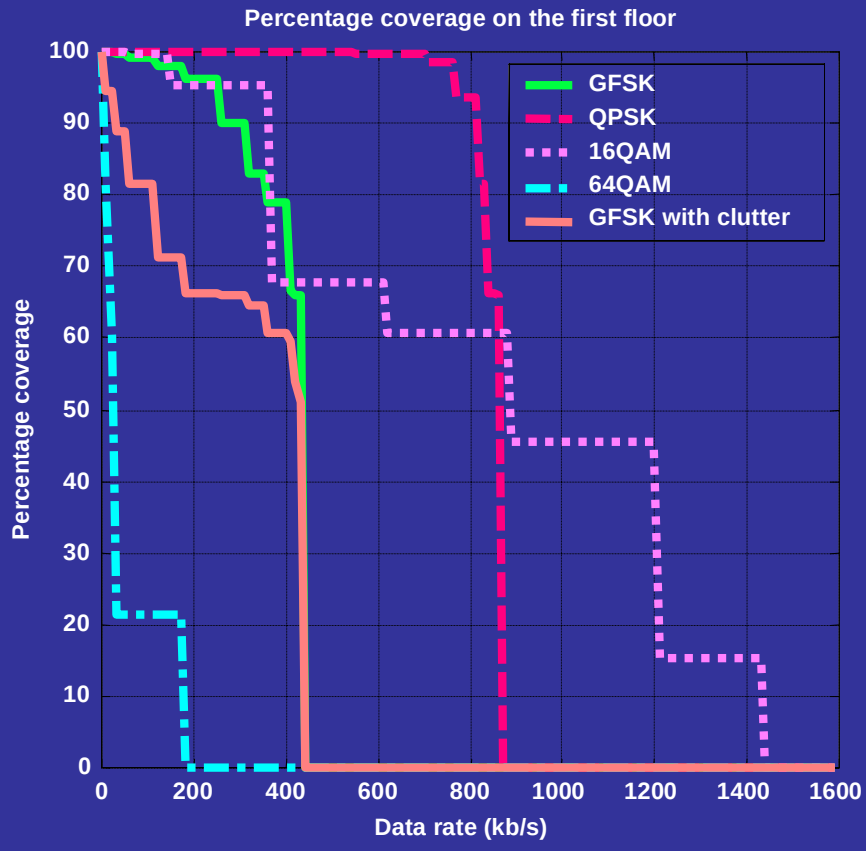
Indoor Space-Time Modeling Tool

- 2 double storey buildings back to back with transmitter on the ground floor
- 1mW peak transmit power (0 dBm)
- Dimensions of the area: 16 x 11m^2 with 3m high ceilings
- Analysis of Data Link plots were done for the ground and first floors of the home environment
- Percentage of coverage on the ground and first floors
- Analysis of clutter for the GFSK system

Coverage Plots for a Double Storey Indoor Home Environment



Ground Floor



First Floor

Summary of applications using different modulation schemes

	Applications using GFSK	Applications using QPSK	Applications using 16QAM	Applications using 64QAM
	400 kb/s	830 kb/s	880 kb/s	20 kb/s
GROUND FLOOR	Non-time bounded applications such as web browsing, cordless telephones (DECT) and videophones, cordless modems and PDAs	Time-bounded applications such as moderately good digital quality video and non-time bounded applications	Time-bounded applications such as moderately good digital quality video and non-time bounded applications	Low data rate non-time bounded applications.
	360 kb/s	820 kb/s	360 kb/s	10 kb/s
FIRST FLOOR	Non-time bounded applications such as web browsing, cordless telephones (DECT) and videophones, cordless modems and PDAs	Time-bounded applications such as moderately good digital quality video and non-time bounded applications	Non-time bounded applications such as web browsing, cordless telephones (DECT) and videophones, cordless modems and PDAs	Low data rate non-time bounded applications.

Interference within a Bluetooth environment

- **Class A: Frequency collision**
  - *depends on the distance and transmit power level*
- **Class B: Spatial interference**
  - *due to strong signal power from neighbouring piconets*
  - *Other WLAN products*

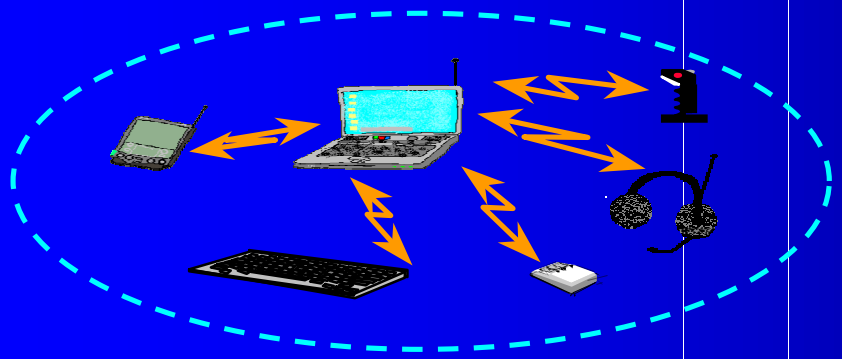
    e.g. Microwave ovens

    Products based on the IEEE 802.11 standard

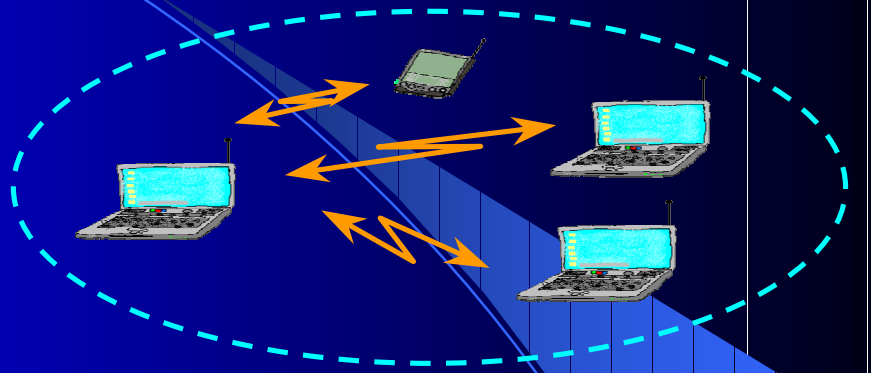
Implemented Frequency Hopping Kernel

- ***First addition:*** Modulo 32 operation.
- ***XOR operation:*** Output of first addition is xor-ed with $A_{22\text{-}19}$ (UAP).
- ***Permutation:*** 7 stages of butterfly operation which switches from 5 inputs to 5 outputs.
- ***Second addition:*** Adds a constant to the output of the permutation operation. The addition is applied modulo 79.
- ***Register bank:*** Contains synthesiser code words which are pointed at by second addition

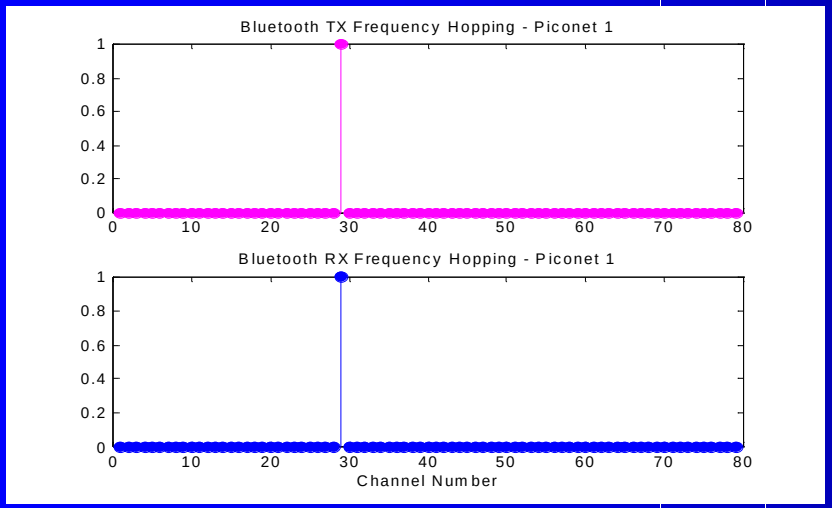
Class A : Frequency Collision

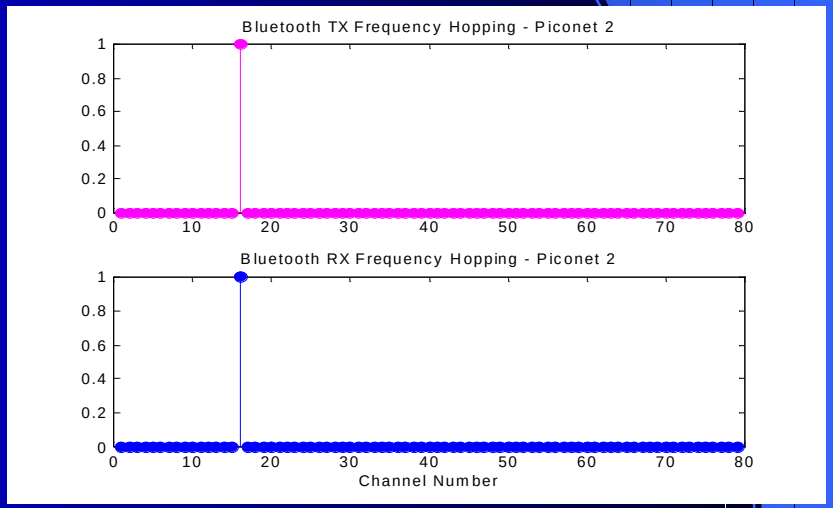


Piconet 1



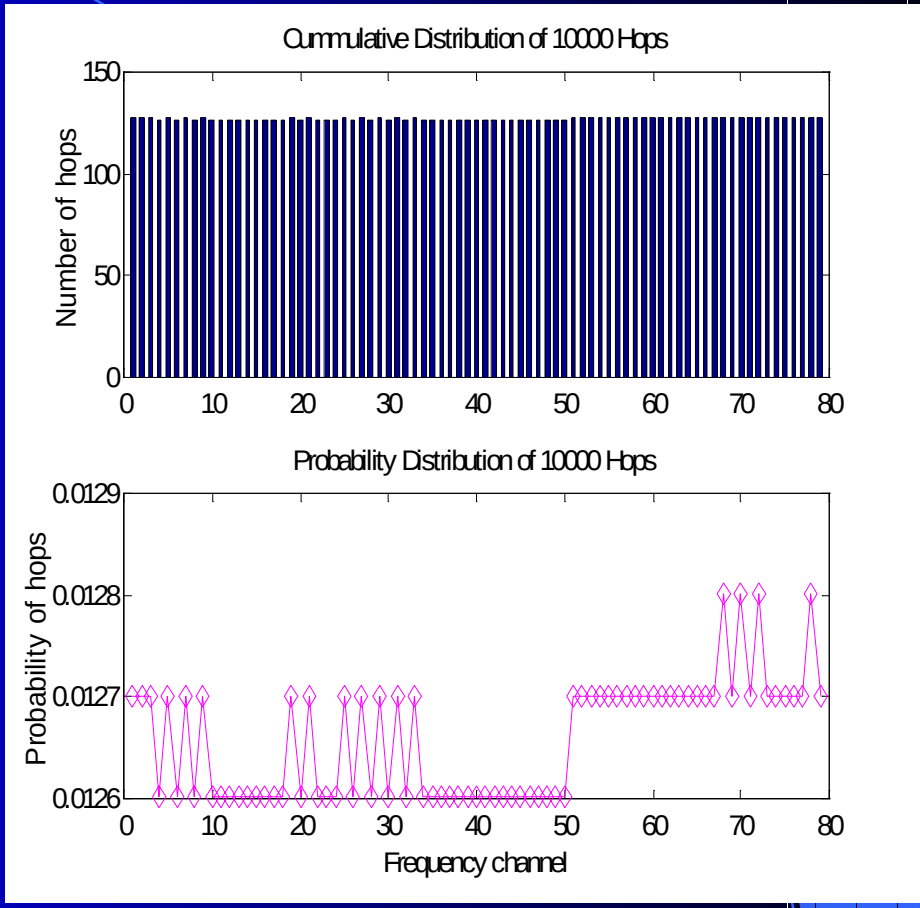
Piconet 2





Preliminary Results

- The number of collisions between any wanted piconet to unwanted piconet is a BD_ADDR dependent phenomena
- Number of collisions between any 2 piconets in an N piconet environment is not fixed
- The interference issues are also dependent on the transmit power level and the C/I and S/N ratios in the environment concerned
- The possibility of using antenna arrays for steering a beam towards the wanted user is a proposal for interference rejection

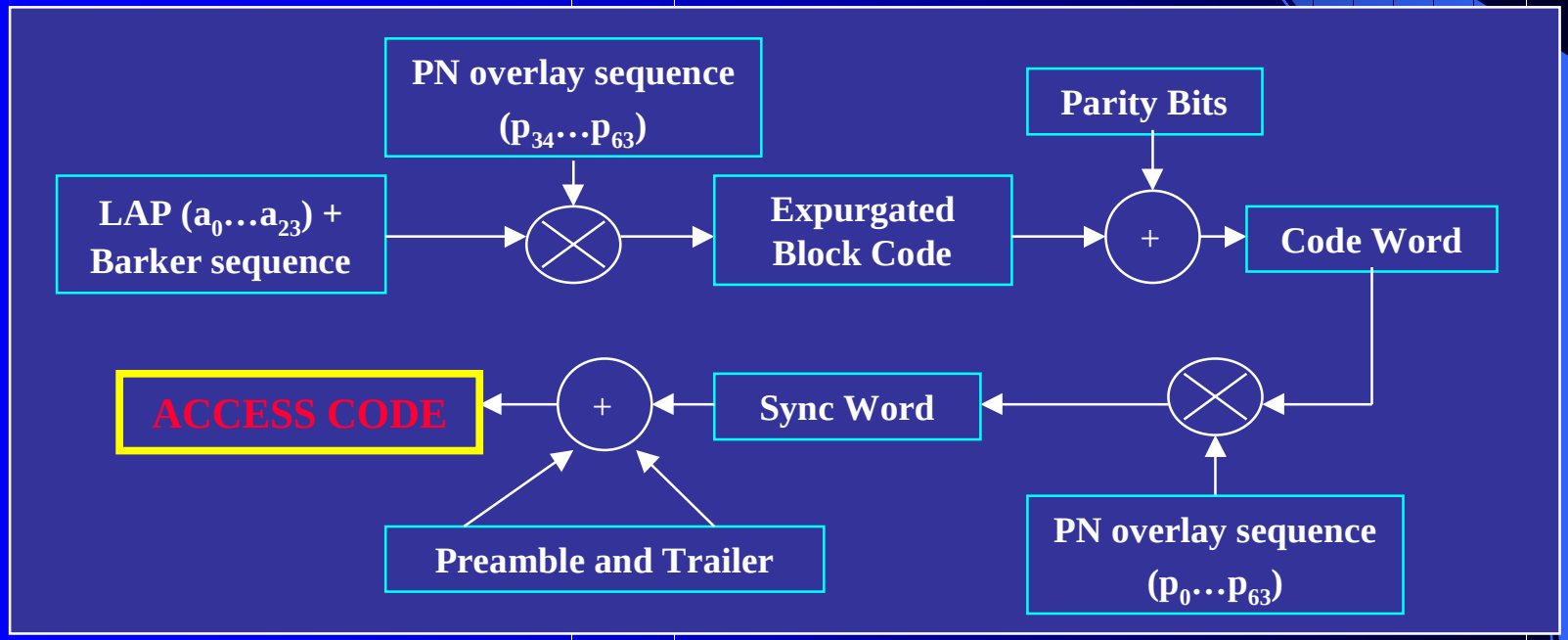


Results show that in 10000 hops, all 79 frequencies are visited approximately 126 times

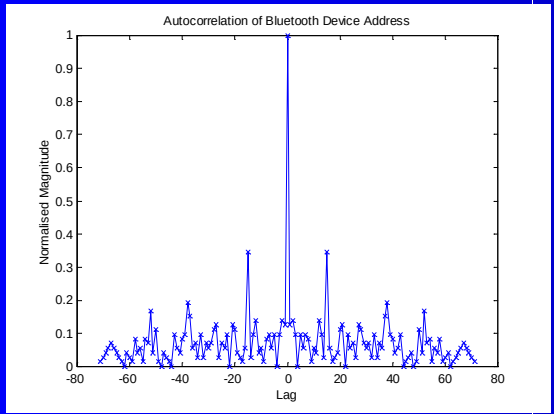
Implemented Bluetooth Addressing Scheme

Lower Address Part (LAP)	Upper Address Part (UAP)	Non-significant Address Part (NAP)
24 bits	8 bits	16 bits

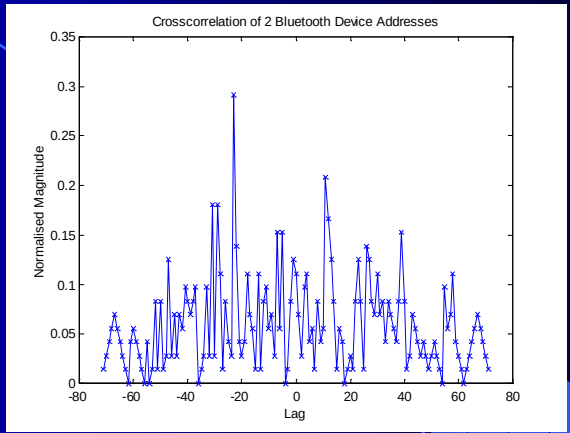
- The sync words are based on a (64,30) expurgated block code with a bit-wise XOR operation of a 64 length PN sequence.



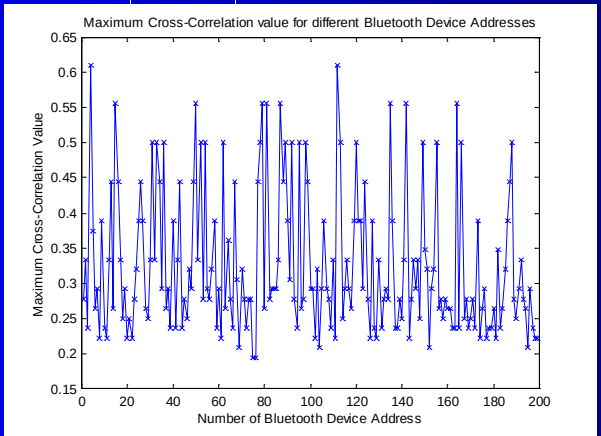
Auto-correlation and Cross-correlation properties in BD_ADDR



(a): Auto-correlation of a BD_ADDR

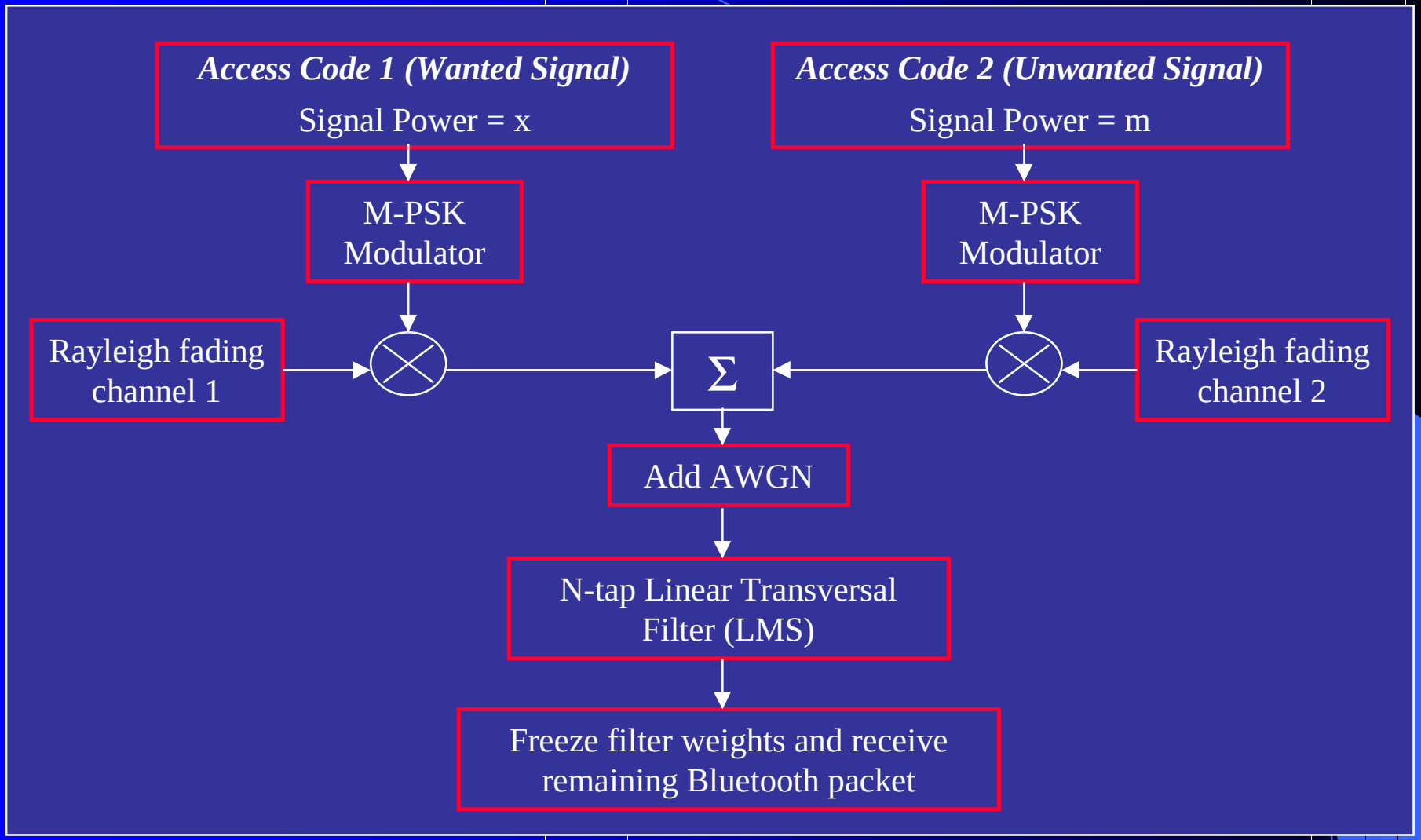


(b) Cross-correlation between 2 BD_ADDR

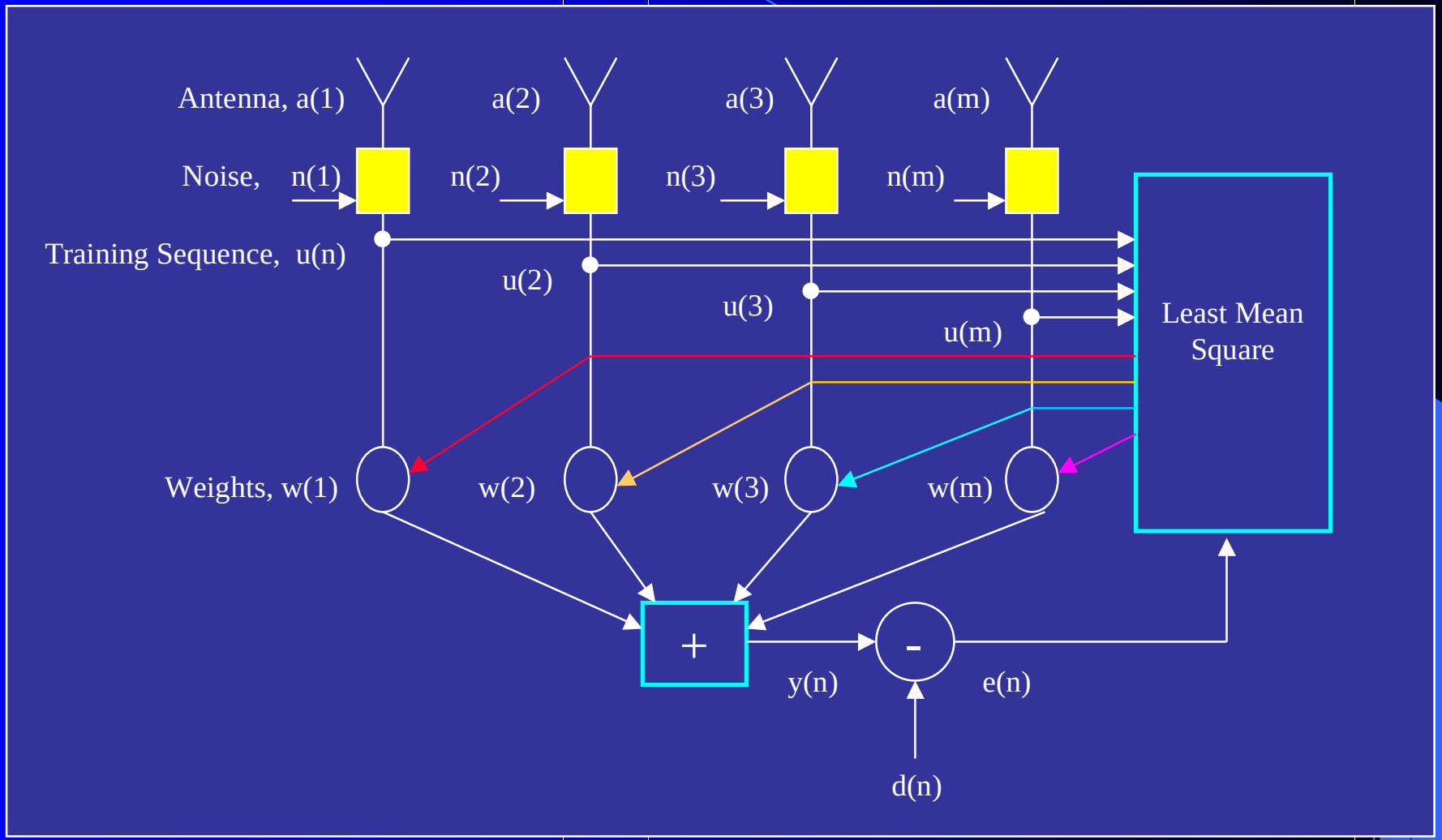


(c) Maximum cross- correlation value for 200 different BD_ADDR

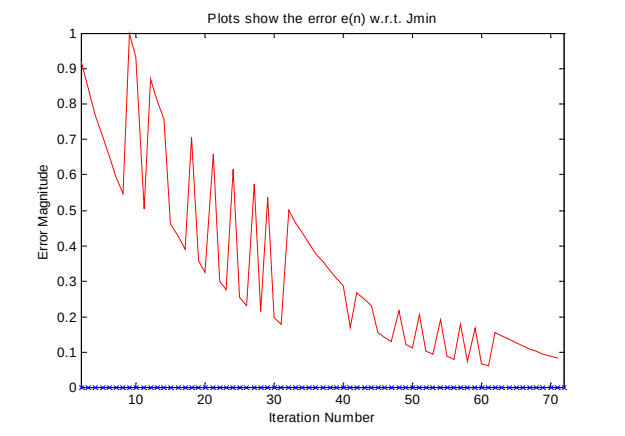
Class B: Spatial Interference



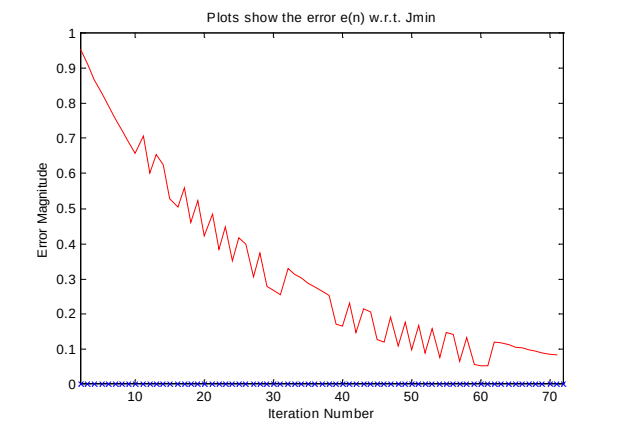
Structure of the Linear Transversal Filter



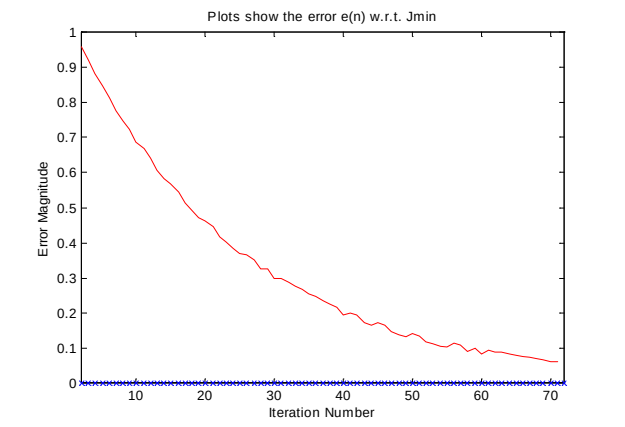
SNR = 50 dB - Single Interference Signal



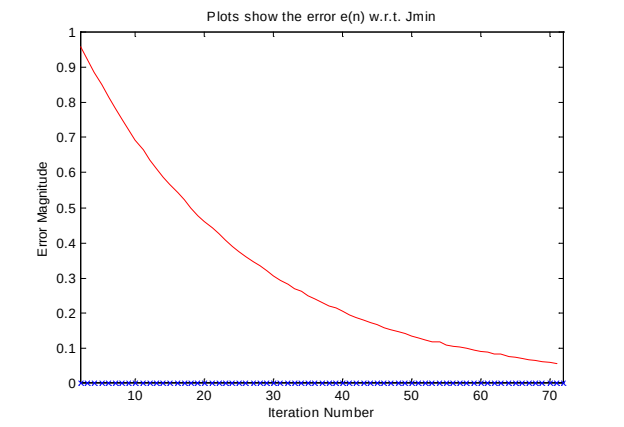
(a) C/I = 0 dB



(b) C/I = 10 dB

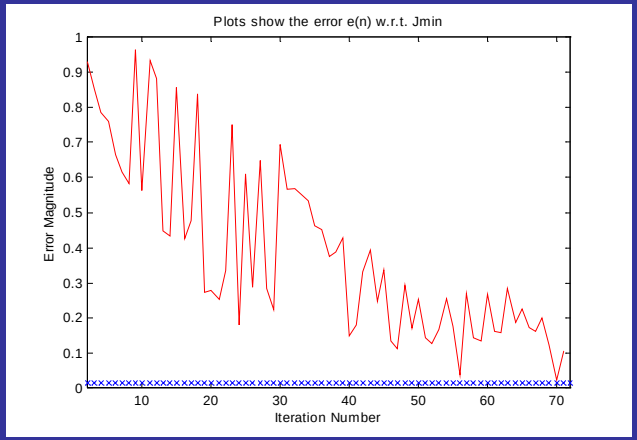


(c) C/I = 20 dB



(d) C/I = 40 dB

SNR = 10 dB - Single Interference Signal



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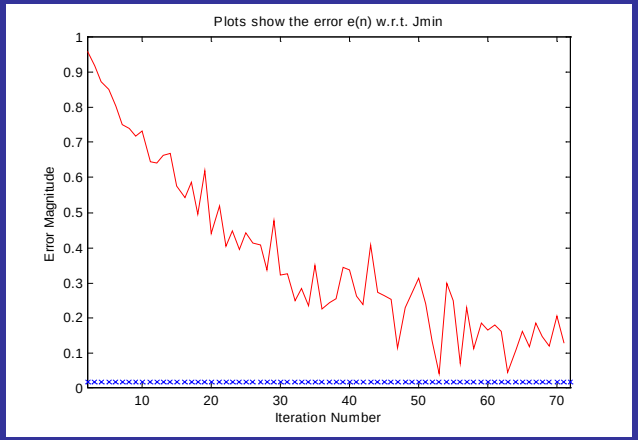
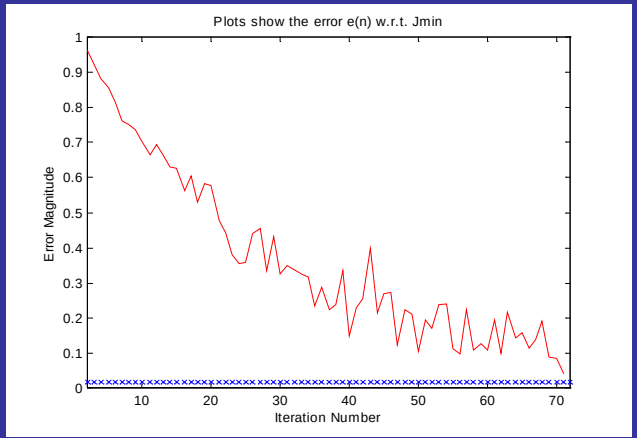
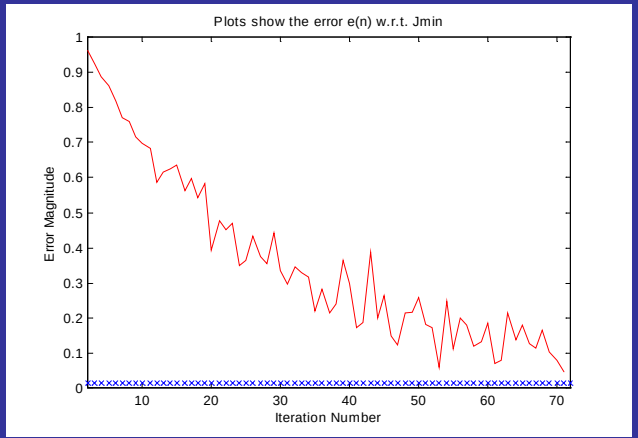


(b) C/I = 10 dB

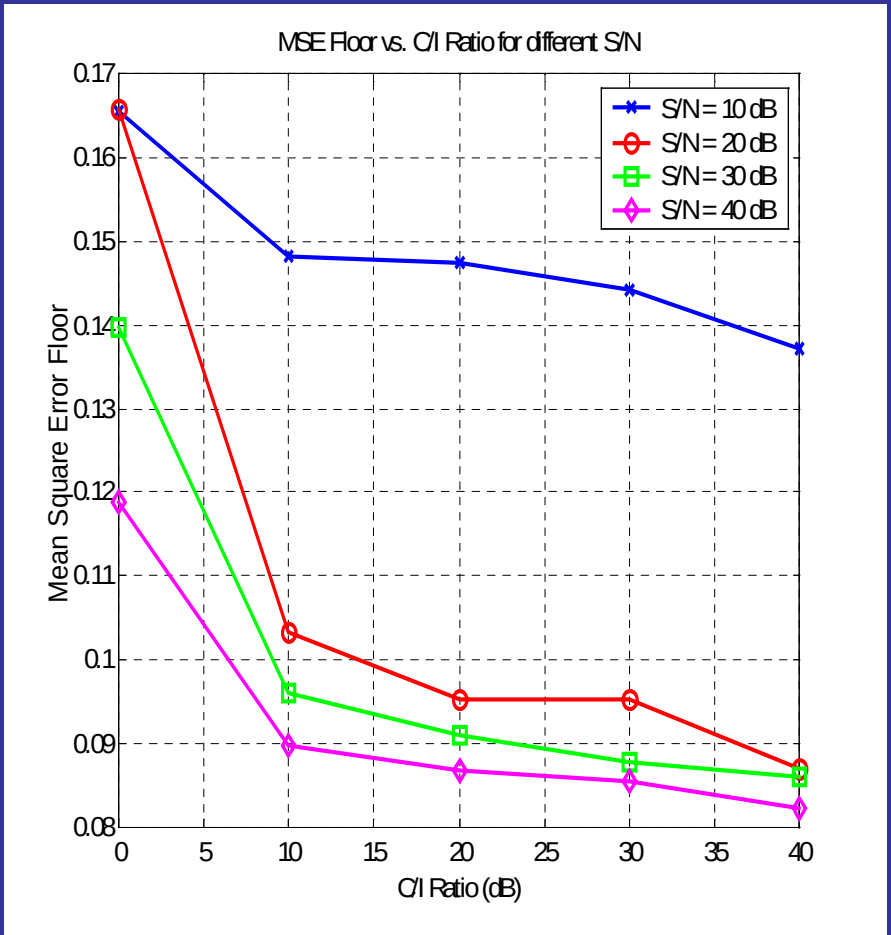


(c) C/I = 20 dB



(d) C/I = 40 dB

Experimental MSE Floor for AC used as a Training Sequence



S/N(dB)	J min	MSE Floor
10	0.015455	0.137179
20	0.001569	0.087018
30	0.000157	0.085944
40	0.000160	0.082201

MSE Floor versus C/I Ratio for different S/N values

Conclusions and Further Work

- PSK schemes are likely candidates for future Bluetooth standards
- The number of collisions between any wanted piconet to unwanted piconet is a BD_ADDR dependent phenomena
- The BD_ADDR shows low cross-correlation properties
- The access code has been found to be successful in training an antenna array
- This suggests that interference present during the training period can be suppressed successfully using this technique
- Further investigation for a M-element antenna array and effects of the step size on the LMS algorithm needs to be carried out for N-interferers
- The above investigation will be incorporated into the simulated Bluetooth base band structure to investigate BER performance within a home environment