IEEE P802.19
Wireless Coexistence

Proposed update for Discovery of Interfering TVBDs				
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Abstract

This document is a submission to IEEE 802.19 TG1 about interferer discovery. This is a follow-up submission to the submission 19-11/0055r0 in which Nokia Research Center provided the interferer discovery algorithm. Different from 19-11/0055r0, the potential interference between two networks are statistically evaluated instead of calculating the worst case of two networks since we believe the probability that the worst case happens is very low, which may result in over estimate the number of neighbors, therefore may increase the difficulty for coexistence decision making.

Introduction

This document discusses potential ways to determine which TVBDs interfere with each other. Now on in this document the process of determining interfering TVBDs is called interferer discovery. Previously this topic has been discussed in document IEEE 802.19-11/0005r1 by AmeriSys and InterDigital and in IEEE 802.19-11/0051r0 and IEEE 802.19-11/0055r0 from Nokia Research Center. This topic was previously called neighbor discovery, and then changed into the term interference discovery due to the feedback received during the May 2001 interim meeting in Indian Wells, CA, USA.

In IEEE 802.19-11/0055r0, they considered the case that the coexistence system services serves Mode I TVBDs, the system design needs to be such that it estimates locations of those Mode I TVBDs and especially those locations in which they would cause most interference to other TVBDs. The interference level of this worst case is then taken as the potential interference between Mode I devices of two networks. The estimation is a good way to determine the interference relationship of two networks, however it may over estimate the number of potential neighbors because the probability that this worst case happens is very low. This may therefore leave a hard job for the following coexistence decision-making.

In this document the potential interference between Mode I devices of two networks are statistically evaluated, The 90% interference level that 90% of devices receives interference equal or less than is taken as a potential interference of two networks. This value is then used to compare with the tolerable interference level of a device to determine interference relationship of two networks.

Input parameters from a CE to the interferer discovery

Following information needs to be considered as input for interferer discovery calculations:

1. Geo-location of the Mode II or Fixed device
2. Environment type
    - Indoor/outdoor, urban/suburban/rural, (office, home, mall, floor number …)
3. HAAT (h_T and h_R)
4. Supported frequencies
5. Reference bandwidth (BW)
6. Receiver characteristics (two alternatives)

- Minimum SINR for the network to operate (SINRmin) and noise figure (NF)
- Minimum receiver sensitivity
  - Is only noise assumed or should some interference also be assumed?

7. Transmitter characteristics
   - Maximum transmission power Ptxmax with antenna properties (see point 7)
   - EIRP
8. Antenna directivity D(θ,)
   - θ is an azimuth angle and is an elevation angle (implicitly included in later equation) and antenna loss La (Combination of directivity and antenna loss is antenna gain)

Formulas for path loss evaluation

Propagation model has an essential role when estimating path loss between a transmitter and a receiver under study. Figure 1 illustrates a model to estimate interference between TVBDs of two networks, A and B. The master of network A and network Bare Fixed or Mode II devices who initial the network A and network B, respectively. Locations of these master TVBDs are known and those are the locations of Fixed or Mode II devices that are using the services of a coexistence system. If a mode II devices act under control of a master device (fixed or mode II) and no other devices depend on the operations and existence of such mode II devices, their location information is not necessary and the same process performs as that to Mode I devices.

Locations of Mode I TVBDs are not known but estimated by coexistence system. In the estimation, we assume that Mode I devices are uniformly distributed within the communication area of their master device (fixed or mode II) in network A and network B as shown in Figure 1. The cumulative distribution function (CDF) of potential interference from Network A to Network B is calculated by coexistence system, and vice versa. The interference level which 90% of devices receive interference equal or less than (refer to 90% interference level in the following context) is then taken as the possible interference value between two networks..

Following aspects needs to be taken into account when evaluating whether TVBDs are interferers or not:

- Propagation model (L(r, x))

- L is attenuation over a certain link between a transmitter and a receiver. The r is the distance between the transmitter and the receiver and x represents all the other parameters that are needed to define the attenuation.

- The following formula can be used to evaluate the attenuation between a transmitter and a receiver

$$L(\ldots) = 10\log(4\pi r/\lambda)^{\alpha} - 20\log(h_T * h_R),$$

in which λ is a wavelength and α is an environment related attenuation exponential (free space = 2, otherwise higher). Operating environment and maximum transmission power should be used to define the value of the attenuation exponential.

- Distribution model

  - Both transmit and receive slave devices (Mode I or Slave Mode II) are assumed uniformly distributed around its master device (Fixed or Mode II) within the communication area.

  - The location of devices can be randomly generated in polar coordinates, with radius r and angle φ following the distribution as.

$$pdf(\varphi) = 1/2\pi$$

$$pdf(r) = (2/R^2)r$$

in which R is a radius of communication area.

- Communication area of a network

  - Communication area is the coverage area that the master devices (Mode II or Fixed devices), provides to their networks.

- Interference area of a network

  - Interference area is the area within which the signal level from any device of the network within the communication area of the network is equal to or larger than N+Im

    i. Im is interference margin that defines how much interference a device tolerates above the noise level from another device at a receiver input before the other device is deemed as an interferer.

    ii. If the specification defines a commonly used Im value for all the networks and users, one can determine the interference area for each network separately without knowledge about the other network and its devices parameters. If each network/device can determine their own interference margin, one needs to determine interference areas for network pairs rather than for individual networks.

- What is the 90% potential interference level from a device in the network A to a device in the network B and vice versa?
    - This may be estimated by considering two randomly located slave devices of two networks, and finds out the interference level that 90% of devices receive interference equal or less than.

      $$Prx = Ptxmax + Gt(\theta\_B) + Gr(\theta\_A) - L(r, x),$$

      where Prx is receive power of a device in either network A or network B, Ptxmax is the maximum transmit power of a device from either network B or network A, respectively.. The L(r, x) represents the path loss between the two devices of two networks, where the distance between two devices of two networks r is calculated based on the randomly generated locations within communication area of two networks.
    - To calculate CDF of potential interference from a device in network A to a device in network B, or vice versa, at least 100 realizations of transmitter and receiver location shall be generated.
    - Figure 2 illustrates an example CDF of potential interference from a device in Network A to a device in network B, where 90% interference level is -93.4977dB. This value is taken as a potential interference between two networks.

With these parameters the CDIS estimates whether a TVBD and potential Mode I devices it may serve can interfere with TVBDs in another network operated by another TVBD connected to a coexistence system. Additionally, the CDIS estimates the interference type (mutual, source, victim) in case there is potential interference between the TVBDs.

Here we haven't considered the frequency that is used in the calculations. We shouldn't leave this entirely up to the implementations since if the range of the supported frequencies is large compared to the center frequency, the outcome of the analysis may vary a lot. We wonder if the specification should give clear rules in which frequencies of the commonly supported frequencies the analysis should be done.

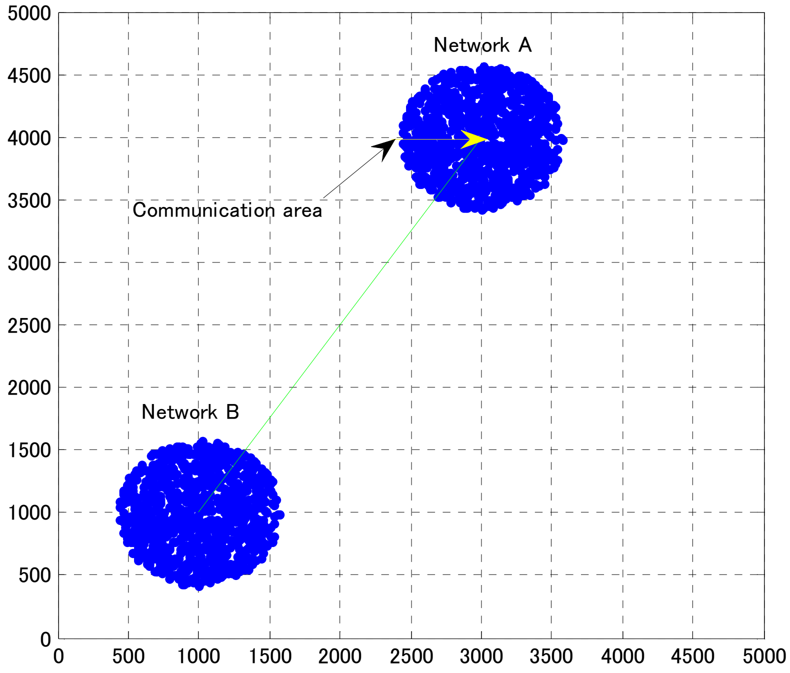

Figure 1: An illustration of interference calculation between two TVBDs representing two networks

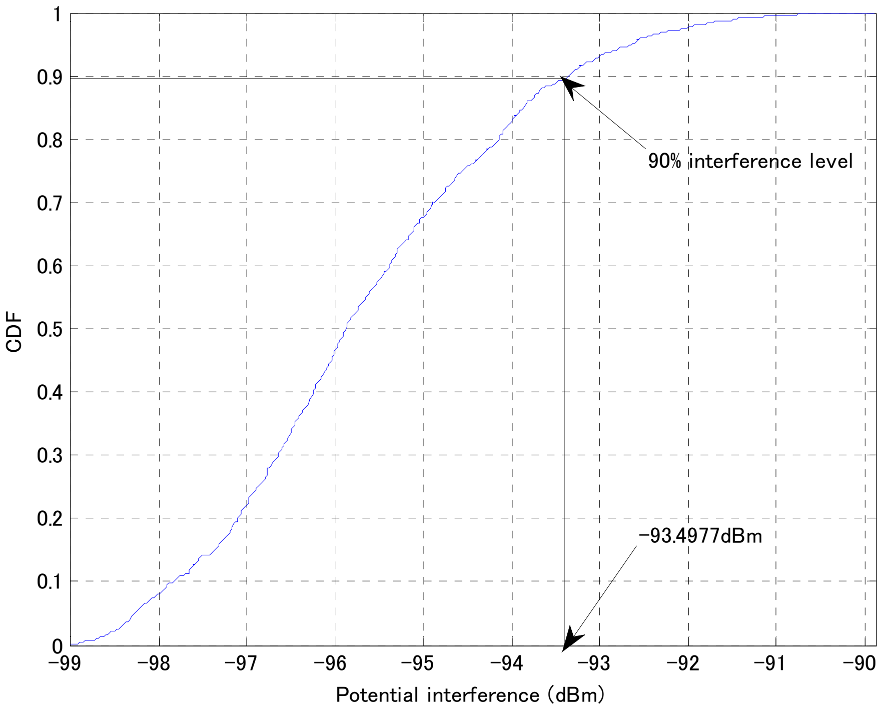

Figure 2: An illustration of CDF of potential interference between two TVBDs in two networks

Interferer discovery procedure

A CDIS performs interferer discovery calculations for each TVBD that has been registered to it. Calculations are done in TVBD pairs and if the TVBDs under consideration serve Mode I TVBDs or Slave Mode II device, the CDIS needs to evaluate 90% interference level of those devices and use those estimates as the interference level between any two Mode I or slave Mode II devices in two networks. Only those TVBDs that have overlap in operating frequency capabilities are taken into account in the evaluation. Their current operating frequency is not considered in the calculations but the TVBDs are considered interferers only if they have potential to operate in a same frequency and interfere.

The procedure is roughly as follows for each TVBD pair:

1. Calculate communication and interference areas for both TVBDs
2. Evaluate the 90% potential interference between two networks for both directions
    a. Prx_ax to represent 90% interference experienced by a device in the network A from a device in the network B
    b. Prx_bx to represent 90% interference experienced by a device in the network B from a device in the network A
3. Decision of interference status between the two networks and devices in them
    - Prx_ax and Prx_bx > Im+N (N=No+NF): Both are interferers to each other (mutual)
    - Prx_ax and Prx_bx < Im+N (N=No+NF): No interference
    - Prx_ax > Im+N and Prx_bx < Im+N (N=No+NF): Network A device is an interference victim
    - Prx_ax < Im+N and Prx_bx > Im+N (N=No+NF): Network A device is an interference source
    - If the communication areas overlap, following short cuts in the decision making can be done
        - If the both networks are serving Mode I devices with unknown location, the networks' devices are deemed interferers.
        - If only one of the networks is service Mode I devices with unknown location, the communication area of that network has to contain a location of a Mode II or Fixed device of the other network and the communication area of the Mode II of Fixed device of the other network has to overlap with the communication area of the first network

Prx above would be actually 10*lg (10^(Prx,calculated/10)+10^(N/10)) when measured in e.g. RSSI.

The outcome of the discovery

The outcome of the interferer discovery is as follows:

1. Interference direction
    - Mutual, Source, Victim
2. Prx_ax and Prx_bx

Annex 1 Simulation results

A simulation is done over a empty area of 5 km by 5 km. We assume that 1~20 IEEE 802.11 networks are randomly distributed over this area, and there are up to 5 active devices in each networks. For each case of different number of networks, 1000 realizations are generated; the results are averaged over the number of realizations in order to get the stable results. The simulation parameters are listed in Table I.

Table I Simulation Parameters

Experiment area	5 km by 5km
Number of networks in the area	1~20
Maximum number of devices per network	5
Network type	IEEE 802.11
Operation Frequency	700MHz
Operation Bandwidth	5MHz
Receive sensitivity	-88dBm OFDM PHY BPSK 1/2 CC 5MHz (802.11-2007 Table 17-13)
Attenuation exponential factor	2.2
Maximum transmit power	100mw
Transmit antenna gain	0dB
Receiver antenna gain	0dB
Transmit antenna height	10m
Receive antenna height	2m
Radius of communication area (calculated)	576.2m
Radius of interference area (calculated)	1079.6 m

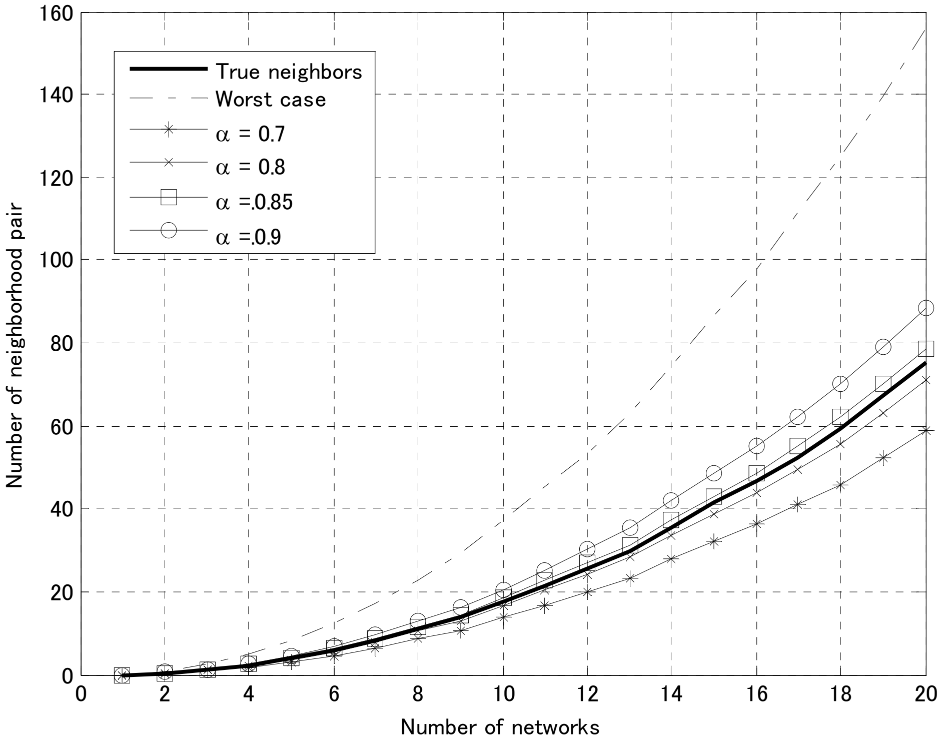

Figure 3 Number of networks VS. Number of neighborhood pair that the system found.

Figure 3 illustrates the number of neighborhood pair that the coexistence system can found. The bold black line is the practical number of neighborhood pairs in the scenarios. The dash-dotted line stands for the way by calculating the worst case interference in those locations in which they would cause most interference to other TVBDs. The other lines present the cases by taking into account of statistics during interference evaluations where α is the percentage as the example in in Figure 2 where the corresponding interference is taken as the potential interference level between Mode I devices in two networks that α percentage of neighbors receive the interference less than or equal to the corresponding interference level. It is shown from this figure that the number of neighbor pairs that the coexistence system finds by considering only the worst case deviate from the practical number as the number of network increases. This means that the worst case interference calculation over-estimate the potential neighbors who may interfere to each other. While we can also see that if α is between 0.8 ~0.9, the estimated number of neighbor pair is much close to the practical number of neighbors pair (interfering TVBD).

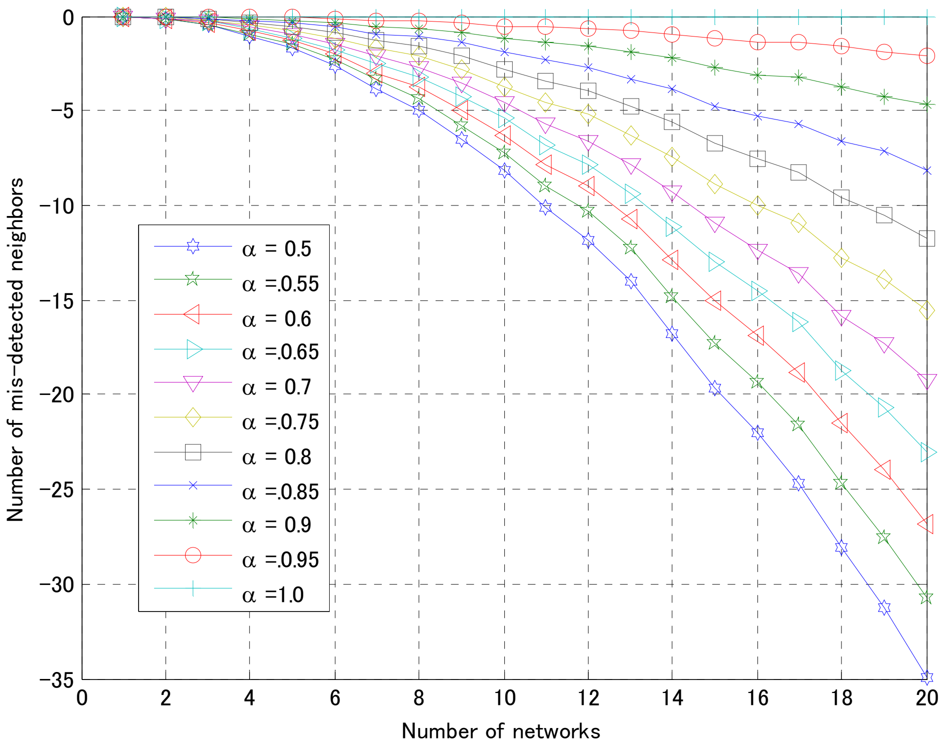

Figure 4: Number of mis-detected neighbors vs. Number of networks

Figure 4 illustrates mis-detected neighbors with respect to the number of networks. The neighborhood mis-detection is defined here as that although a TVBD in one network does cause interference to a TVBD in another network, the coexistence system makes a wrong decision from them as no interference. Then we call this as mis-detection. Since the way by considering the inference in those locations which causes most interference is to calculate the worst case, the mis-detection is zero. In this figure, only absolute value is meaningful, the negative symbol is just to make the figure different from the figure of false alarm. It is also shown in the figure that as the α increases, the mis-detection gets close to zeros gradually.

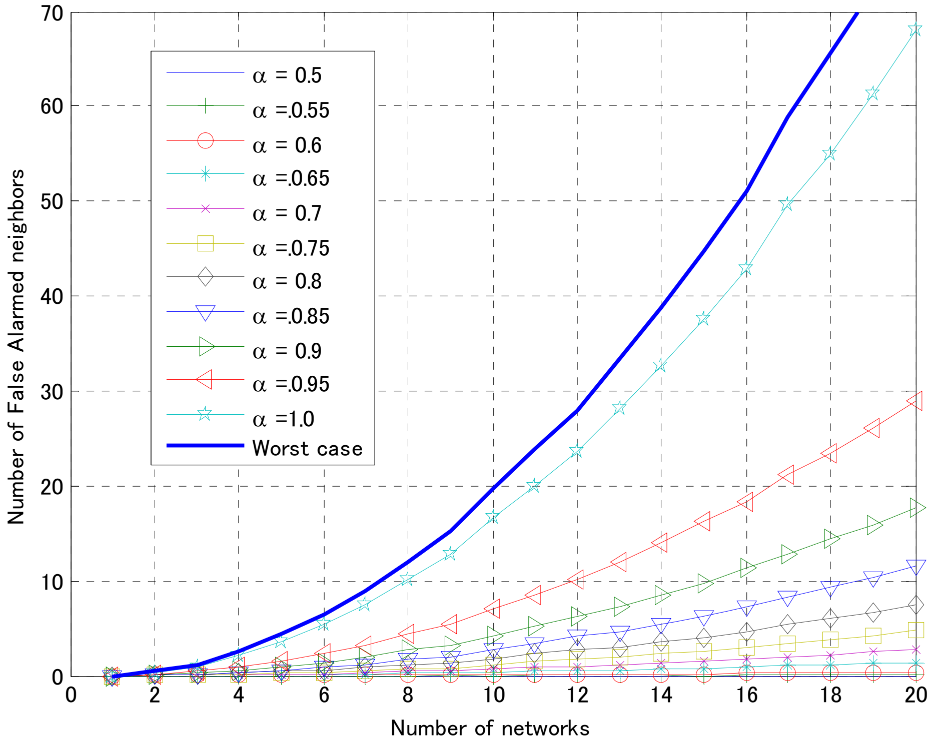

Figure 5 Number of False Alarmed neighbors vs. Number of networks

Figure 5 illustrates the number of false alarmed neighbors with respect to the number of networks. The neighborhood false alarm is defined here as that although a TVBD in one network does not cause interference to a TVBD in another network, the coexistence system makes a wrong decision for them as interfering TVBD, then we take this as false alarm. The bold blue line is for the way when the worst case interference is considered; we can see the worst case interference calculation almost double the number of interfering neighbor pair. The other lines are for the cases when statistics is taken into account. It is shown that as the α inceases, the false alarm rate goes higher.

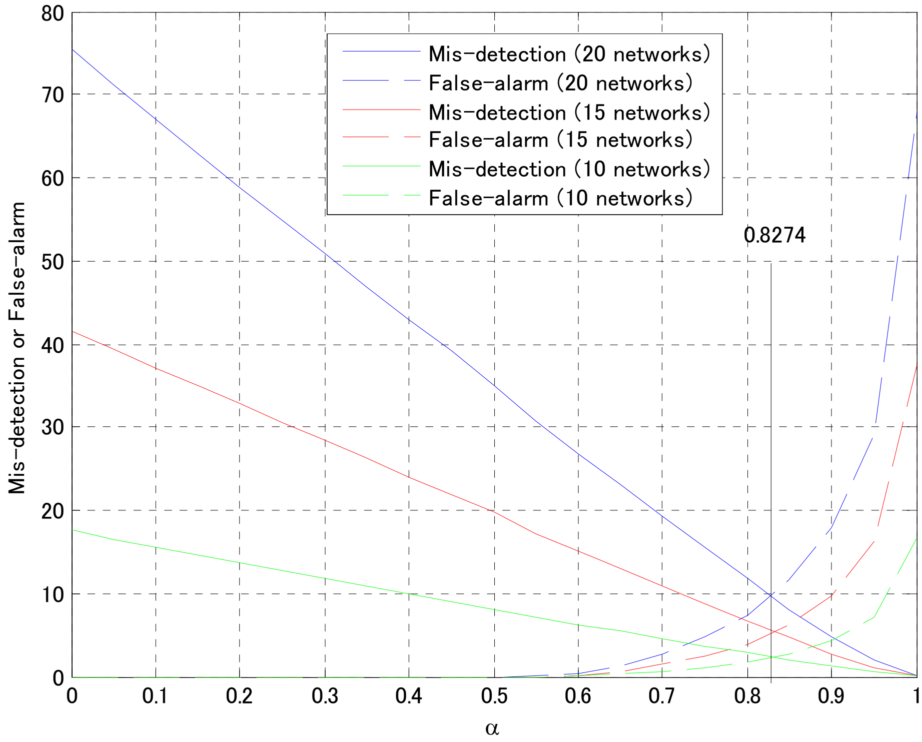

Figure 6 Percentage of Mis-detection or false alarm vs. percentage for interference level selection

In Figure 4 and Figure 5, we know that as α increases, the mis-detection rate goes to zero, while false alarm goes higher. Therefore there may be an optimum point where both mis-detection and false alarm keep low and acceptable. Figure 6 illustrate mis-detection and false alarm with respect to the percentage of interference level, that is, α. We see that if $\alpha = 0.8274$, it achieves optimum point where both of mis-detectiion and false alarm are low. In our propose, we select $\alpha = 0.9$ which makes the mis-detection ever lower and makes false alarm bigger since a little larger false alarm may not impact the system's performance very much.