A Novel Utilization of Hop Rate Detector to Differentiate Between Signals in Noisy Environment

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Summary

One of the most challenging topics for next generation wireless networks is the process of discrimination among signals, since many of wireless technologies overlap each other and build a heterogeneous topology. The conventional signal's detection methods like Matched Filter detector, Energy Detector and Feature Detector cannot give us an indication about the type of signals. Also suffer from many drawbacks like complexity in design, determining the value of threshold level and increasing probability of false alarm (P_f) in high noise level etc. This work considered the recognition between GSM and WiMAX signals in noisy environment. Our discriminator (Bouncy Detector (BD)) is an extension for Hop Rate Detector's (HRD). It was basically designed to detect and estimate the hop rate of frequency hopping signals only. The simulation results show that BD can work properly and accurately in highly noise environment without perplexity.

Key words:

Hop Rate Detector (HRD); Bouncy Detector (BD); GSM, WiMAX, WCCAIS2014.

1. Introduction

The future beyond third Generation (B3G) or fourth Generation (4G) mobile networks will consist of heterogeneous networks, including Global System for Mobile Communication (GSM), Worldwide Interoperability for Microwave Access (WiMAX) and Universal Mobile Telecommunications System (UMTS). With the advancement of those technologies, mobile communication has been providing more versatile, portable and affordable networks services than ever. Therefore, the number of mobile users (MUs) communication networks has increased rapidly. But those systems use only a small fraction of their allocated bandwidth. Cooperative systems can make use of unallocated transmission capacity in under-utilized frequency bands without causing significant interference. It is widely accepted by all players that no single mobile wireless technology will prevail on the expense of the others in the foreseen future. Thus the novelty in future networks is in facilitating the coexistence of different technologies not in waging competition between them. In the European Conference of Postal and Telecommunications Administrations (CEPT) the frequency bands 880-915 MHz (Uplink) and 925-960 MHz (Downlink) are allocated to mobile services and are currently used for (GSM) and (UMTS) networks but also planned for the usage by Long Term Evolution (LTE) and (WiMAX) and in the future other public mobile networks [1]. Multiple wireless interfaces like (GSM), Wireless Fidelity (Wi-Fi), Bluetooth, and Global Positioning System (GPS) receiver, etc. are being integrated into mobile devices. WiMAX, an IEEE802.16-based wireless access technology recently included in the IMT-2000 set of standards by ITU-R, will soon be added. But main problem is that how to operate these radios networks concurrently without interference and hardware conflicts due to congested spectrum allocation and component sharing with radio integration [2].

Today, different types of cellular networks are actively working on the radio links. For instance, the GSM is being used in nearly all of the countries of the world; it has around three billion users all over the world. It is the fully digital system it is considered as a 2G standard and was driven by ETSI (European telecommunication standard institute), which is evolution of (1G) analog system using 900, 1800 MHZ frequency bands. It has become popular very quickly because it provides improved speech quality and, a uniform international standard, makes it possible to use a single telephone number and mobile unit around the world.

The use of Frequency Hopping (FH) in GSM is the most important FH application. FH can introduce frequency diversity and interference diversity. It can be an effective technique for combating Rayleigh fading, reducing interleaving depth and associated delay, and enabling efficient frequency reuse in a multiple access communication system. Frequency Hopping Spread Spectrum (FHSS) technique has been used widely not only in public safety communications but also in commercial communications such as home RF and Bluetooth, with interference avoidance and multiple access capability [3].

WiMAX Forum is a worldwide organization created to promote and certify compatibility and interoperability of broadband wireless products based on the IEEE 802.16 standard. Evolution and deployment of WiMAX technology rely on cooperative and complementary efforts in the WiMAX forum and IEEE 802.16 standard. The important features of WiMAX are scalable OFDMA, multiple input multiple output (MIMO) antenna, beam forming and adaptive modulation and coding (AMC), support time division duplexing (TDD) and frequency division duplexing (FDD), space time coding, strong security and multiple QoS classes [4-6].

In these cellular technologies and others, we have very limited resources and we have to make best use of them by proper management. The types of signals that presented in the environment are important to be known for the interceptors, cognitive users (CU) and other spectrum's users. This enables us to exploit the unutilized available spectral resources in different manner. Nowadays many commission and researchers are trying to use (800MHz) of TV for WiMAX, LTE and GSM. After switching to this band, the frequencies will become very convergence or very close and it is unavoidable to interfere the neighbouring commercial mobile networks when mobile systems are deployed. However efforts are made by different workers to maximizing the spectrum utilization with minimum interference [7, 8]. The main objective of researchers is to scan the spectrum, detect the type of signals and differentiate among them. So our new detector (BD) can be used to differentiate between GSM and WiMAX signals accurately. Since those technologies are hardly available today with commercially available devices, a simulation model is not far to seek. Thus, we implemented a simulation in Matlab framework in order to investigate and evaluate the performance of BD detector.

2. Literature Survey

Yi Zhang and et al [9] studied the problem of co-existence with other mobile systems. They started with the realistic problem, and provided the detailed research method and simulation results. Guihua Piao and David, K. [10] studied Multi-standard radio resource management (MxRRM), based on a user data rate optimised algorithm, for non-real-time (NRT) services in a heterogeneous WiMAX/ UMTS/GSM scenario. They used an algorithm using a parameter, namely NRT load information, which is mapped from the average user throughput in a respective network. The performance level of MxRRM is assessed through a network simulator. The load redistribution, the mean data rate and the intersystem handover activity are investigated in three scenarios: a) completely separate systems, b) separate WiMAX and MxRRM for GSM and UMTS, and c) MxRRM for these three radio access networks. Shaukat R. and Cheema A.R. [11] dealt with the issue of interoperability between heterogeneous networks using Mobile IP. They mentioned some handover solutions based on prior networks between GSM and WiMAX. Where GSM is circuit switched based network while WiMAX is packet switched network. Both technologies use different infrastructure but both support Mobile IP. Weiss J. et al. [12] elaborated that the remaining transmission resources in GSM frequency range. Therefore, it can be used as an exemplary licensed user system with burst traffic and varying usage rates providing a reasonable remaining capacity that can be utilized by an overlay system. WiMAX provides a highly flexible solution that can be adapted to the specific requirements of an overlay system. So by adding elements for signalling of the current spectrum usage of the underlying GSM system to the WiMAX frame, the WiMAX overlay system is able to react very fast to changing utilizations of the spectrum. In 2009, K. Sridhara et al [13] found out the distributed server-based dynamic spectrum allocation (DSA) within liberalized spectrum sharing regulation concept as an alternative to existing regulation based on fixed frequency spectrum allocation schemes towards development of cognitive. They investigated a scenario where a block of spectrum is shared among four different kinds of exemplary air interface standards i.e., GSM, CDMA, UMTS and WiMAX. Two mechanisms [14] have been proposed independently by IEEE and 3GPP; namely, Media Independent Handover (MIH) and Access Network Discovery & Selection Function (ANDSF), respectively. These mechanisms enable a seamless Vertical Handover (VHO) between the different types of technologies (3GPP and non-3GPP), such as GSM, Wireless Fidelity (WiFi), WiMAX, UMTS and LTE. Adaptive fuzzy logic based vertical handoff decision making algorithms [15] are presented for wireless overlay networks which consist of GSM/GPRS/Wi-Fi/UMTS/WiMAX technologies. The parameters as data rate, monetary cost, speed of mobile and Received Signal Strength Indication (RSSI) information are processed as inputs of the proposed fuzzy based systems. It showed that, compared to the traditional RSSI based algorithm significantly enhanced outcomes can be achieved for both user and network as a consequence of the proposed fuzzy based handoff systems.

A variety of interworking architectures and inter-RAT (Radio Access Technology) handover mobility managements have been proposed in [16], in order to realize a seamless vertical handover. It considers the tight coupling architecture to achieve the interconnection between UMTS and WiMAX systems. It proposed novel common interworking sublayer (IW sublayer).

Researchers from previous related works went through coexistence, RRM, interoperability, DSA and VHO problems among different types of technologies. The renovation in this article is how to differentiate between GSM and WiMAX signals in noisy environment accurately.

3. Conventional Signal's Detection Methods

In order to avoid the harmful interference to the primary system, the cognitive radio needs to infer about the availability of the spectrum. There are various methods for spectrum sensing like: energy detection, matched filter detection and cyclostationary detection.

3.1 Energy Detector

Energy detection is a non coherent detection technique in which no prior knowledge of pilot data is required. The detection is based on some function of the received samples which is compared to a predetermined threshold level. The signal detection problem led us to a binary hypothesis-testing problem. In this problem, we need to decide between two hypotheses, the signal is not present (the observation consist of noise only (N[n])) or the signal is present.

H_0: Y[n] = N[n] signal is not present
H_1: Y[n] = X[n] + N[n] signal is present
n = 1,…, N; where N is observation interval (1)

The noise is assumed to be additive white Gaussian noise (AWGN) with zero mean and variance (σ_w^2). The detection (P_d) and false alarm (P_f) probabilities are given as in (2) and (3) where (P_r) is the received power, (λ) denotes the threshold level, (v) is the energy detector output, Γ (x) and Γ (x, y) are the complete and incomplete gamma functions respectively, (W) is the signal bandwidth, (T) signal duration and (γ) is defined as μ/2.

$$P_f = P_r\ (v > \lambda: H1) = [\ \Gamma(TW/2, \lambda/2)/(\ \Gamma(TW)\ )\ ] \quad (2)$$
$$P_d = P_r\ (v > \lambda: H0) = Q_{TW} \quad (3)$$
$$P_m = 1 - P_d \quad (4)$$

Where, P_m denotes the probability of missed detection.

The fixed threshold (λ) is determined by the false alarm probability (P_f) and the number of sample points (N). It can be calculated as follows [17]

$$\lambda = Q^{-1}\ (P_f) + N \quad (5)$$

$$\text{where} \quad Q(x) = 1/\ (\sqrt{2\pi})\ \int_X^{\infty} \exp(-u^2/2)\ du \quad (6)$$

An increased sensing time is not the only disadvantage of the energy detector. More importantly, there is a minimum SNR below which signal cannot be detected. This minimum SNR level is referred to SNR_{wall}. There are two very strong assumptions. First, assuming a white noise additive and Gaussian with zero mean and known variance. However, noise is combination of various sources including not only thermal noise at the receiver and underlined circuits, but also interference due to nearby unintended emissions, weak signals from transmitters, etc. Second, assuming that noise variance is precisely known to the receiver, so that the threshold can be set accordingly. However, this is practically impossible as noise could vary over time due to temperature change, environment interference, filtering, etc. Even if the receiver estimates it, there is a resulting estimation error due to limited amount of time [18-20].

3.2 Matched Filter Detector

Matched filter detection is the optimal way for any signal detection, since it maximizes received signal-to-noise ratio. It is generally used to detect a signal by comparing a known signal with the input signal. However, a matched filter effectively requires demodulation of a received signal. This means that receiver has a priori knowledge of received signal at both PHY and MAC layers, e.g. modulation type and order, pulse shaping, packet format. Such information might be pre-stored in its memory. This is still possible since most transmitted signals have pilots, preambles, synchronization words or spreading codes that can be used for coherent detection. The main advantage of matched filtering is the short time to achieve a certain probability of false alarm or probability of miss detection as compared to other methods that are discussed in this section [19-21].

3.3 Feature Detection or Cyclostationarity-Based Sensing

Cyclostationarity feature detection is a method for detecting transmitted signal by exploiting the cyclostationarity features of the received signals. The transmitted signal generally has a periodic pattern. This periodic pattern (cyclostationarity characteristic), can be used to detect the presence of a signal in the spectrum. A signal is cyclostationary (in the wide sense) if the autocorrelation is a periodic function. With this periodic pattern, the transmitted signal from a licensed user can be distinguished from noise, which is a wide-sense stationary signal. In general, cyclostationary detection can provide a more accurate sensing result and it is robust to variations in noise power. However, the detection is complex and requires long observation periods to obtain sensing result [20, 21].

Conventional signal detection methods have several drawbacks as discussed above. So we propose the extension of the work of Hop Rate Detector (HRD) and exploit it for differentiation and discrimination process between GSM and WiMAX signals.

4. Bouncy Detector

A block diagram of BD is shown in Fig. 1 [22-24]. The whole input band (W_{ss}) is subdivided into two sequential half bands (an upper band (B.sub.u) and lower band (B.sub.d)), and the signal is collapsed by magnitude squaring. The outputs of the squaring devices are then subtracted to form a bipolar signal. The input signal hops randomly between the two half bands, and thus the first stage output signal is a random direct sequence (DS) waveform with transitions occurring at the hop rate. The BD generates a spectral line at the hop rate with a delay-and-mix circuit, with the delay set to approximately $T_h/2$. However, the BD delay-and-mix circuit generates a square wave with one-half the input signal amplitude, and thus one-fourth the signal power. The delay and multiply circuit involves a delay circuit which feeds a first signal input to the multiplier. The second input to the multiplier comes direct from the LPF, to provide the final output of signal-to-noise ratio SNRo.

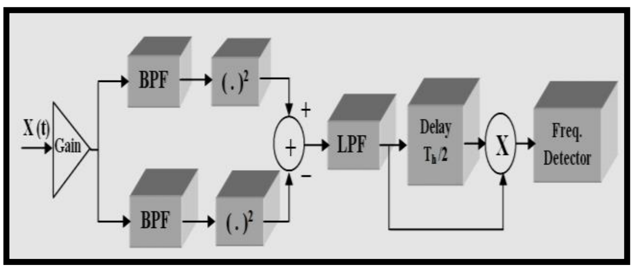

Fig.1 Block diagram of Bouncy Detector (BD)

The probability of crossing the threshold while the FH signal is "present" is much higher than for the "noise only" case and thus, with L_{th} properly set (L_{th} is the threshold level that depends on the input signal-to-noise ratio), the detector sensitivity can be improved. Though amplitude information is lost by single-bit quantization, it may be understood that, while the signal is present in a particular channel, the signal at the output of the squaring device unit is a DC level. It can thus be seen that information relating to the presence of "signal" is preserved by single-bit quantization of the channel.

The term "false alarm" is used to denote the crossing of a threshold value "L_{th}" when no-signal is present in the channel. The optimal probability of a "false alarm" is designated as p_{opt} [24].

$$p_{opt} = e^{-\frac{L_{th}}{2\sigma L}} \qquad (7)$$

The detection probability "q" is the probability that the threshold value L_{th}, will be crossed when a signal is present in the channel. The "first stage" signal-noise ratio, SNR_f can be written:

$$SNR_f = (p-q)^2 / ((L - 1)(p - p^2) + (q - q^2)) \qquad (8)$$

Where (p) is probability of false alarm; and (q) is probability of detection. This equation for SNR_f can be mathematically optimized, and by using various numerical techniques and graphically plotted charts, the optimal probability of false alarm, p_{opt} as a function of input signal-noise ratio, SNR_i, for different values of L (number of BPFs branches) , is shown in figure (2).

Thus given the optimal probability of a false alarm, p_{opt}, as a function of the input signal-noise ratio, SNR_i, then the detection probability (q), can be calculated and plotted as shown in figure (3):

$$q = Q\left(\frac{|A|}{\sigma l}, \sqrt{-2\log p}\right) \qquad (9)$$

where A = signal at output of squaring device, and Marcum Q function is

$$Q = Q(X,Y) = \int_{y}^{+\infty} r e^{-(x2+r2)/2} * Io(xr) dr \qquad (10)$$

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Io= Modified Bessel function of first kind - order 0;

x = First variable of Marcum-Q function;

y = Second variable of Marcum-Q function;

r = Dummy variable for integration;

e = Mathematical-transcendental number value;

dr = Differential of r

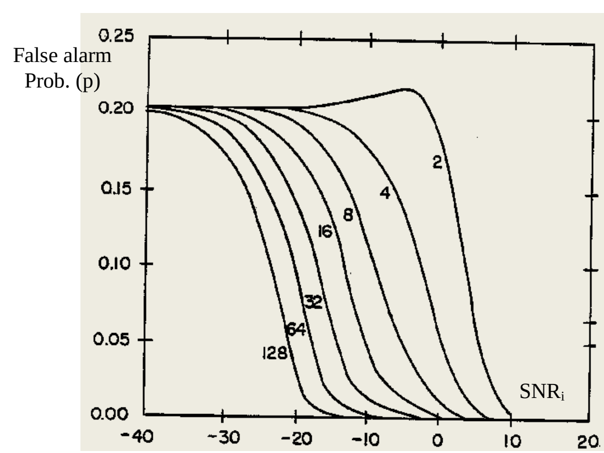

Fig. 2 Optimal false alarm probability (popt) as a function of input signal-noise ratio for various values of L [24]

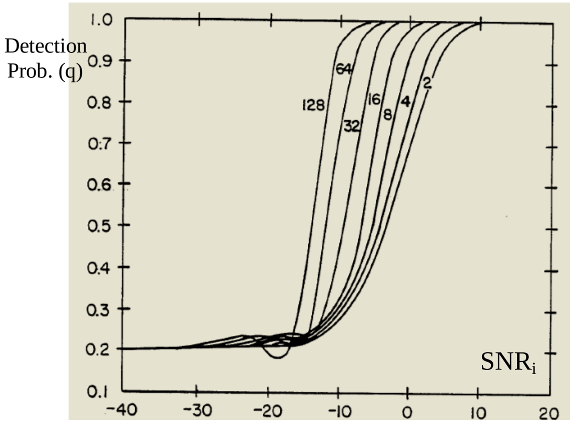

Fig. 3 Optimum detection probability (q_{opt}) as a function of input signal-noise ratio for various values of L [24]

5. System Model

GSM-FH transmitter, WiMAX transmitter and noisy channel have been designed using Matlab Simulink as shown in figure (4).

5.1 GSM Transmitter

The GSM Air-interface uses two different multiplexing schemes: TDMA (Time Division Multiplexing) and FDMA (Frequency Division Multiplexing). The spectrum is divided into 200 kHz channels (FDMA) and each channel is divided into 8 time slots (TDMA). Each 8 time slot TDMA frame has a duration of 4.6 ms (577 micro sec./ time slot). The GSM system uses slow frequency hopping which means that the frequency changes after each burst (once every 4.6 ms). Although the use of FH is optional in GSM but all phones must support it. All physical channels except the 0 time slot of Broadcast Control Channel (BCCH) can hop. A 6 bit hopping sequence is transmitted on a BCCH and both mobile station (MS) and Base Transceiver Station (BTS) have a frequency list indication to which frequencies and in which order to hop.

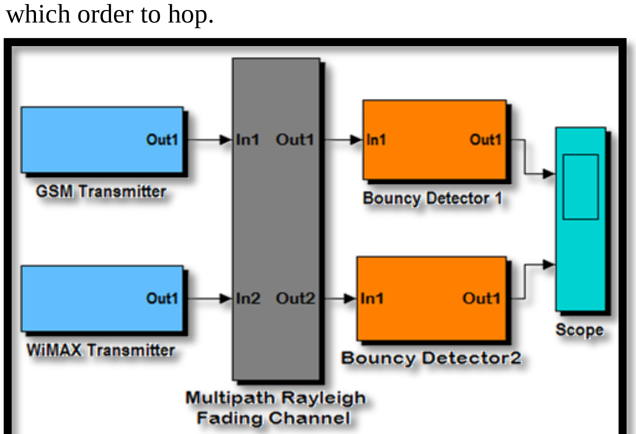

Fig. 4 FH-GSM and WiMAX Transmitters' Matlab Block Diagram

5.1.1 Hopping Sequence Generation

The hopping sequence use up to 64 different frequencies, with speed of just over 200 hops/s. For a given set of parameters, the index to an Absolute Radio Frequency Channel Number (ARFCN) within the mobile allocation indexing (MAI), (MAI from 0 to N-1, where MAI=0 represents the lowest ARFCN in the mobile allocation (MA), ARFCN is in the range 0 to 7023 and the frequency value can be determined with n= ARFCN and $1 \le N \le 64$), is obtained with the following algorithm [25]:

If HSN= 0 (cyclic hopping) then :
MAI, integer (0 ... N-1) : MAI = (FN + MAIO) modulo N
else:
M, integer (0 ... 152) : M = T2 + RNTABLE (table I)* ((HSN XOR T1R) + T3)
S, integer (0 ... N-1) : M' = M modulo (2 ^ NBIN
T' = T3 modulo (2 ^ NBIN)
If M' < N then:
S = M'
else:
S = (M'+T') modulo N
MAI, integer (0 ... N-1) : MAI = (S + MAIO) modulo N

where:

HSN	Hopping Sequence Number
FN	TDMA Frame Number
T1R	Time parameter T1, reduced modulo 64 (6 bits)
T3	Time parameter, from 0 to 50 (6 bits)
T2	Time parameter, from 0 to 25 (5 bits)
NBIN	Number of bits required to represent: N = INTEGER($\log_2(N)$+1)
XOR	Bit-wise exclusive OR of 8 bit binary operands

Table 1: RNTABLE: defined table of 114 integer numbers

Address	Contents
000...009	48, 98, 63, 1, 36, 95, 78, 102, 94, 73
010...019	0, 64, 25, 81, 76, 59, 124, 23, 104, 100
020...029	101, 47, 118, 85, 18, 56, 96, 86, 54, 2
030...039	80, 34, 127, 13, 6, 89, 57, 103, 12, 74
040...049	55, 111, 75, 38, 109, 71, 112, 29, 11, 88
050...059	87, 19, 3, 68, 110, 26, 33, 31, 8, 45
060...069	82, 58, 40, 107, 32, 5, 106, 92, 62, 67
070...079	77, 108, 122, 37, 60, 66, 121, 42, 51, 126
080...089	117, 114, 4, 90, 43, 52, 53, 113, 120, 72
090...099	16, 49, 7, 79, 119, 61, 22, 84, 9, 97
100...109	91, 15, 21, 24, 46, 39, 93, 105, 65, 70
110...113	125, 99, 17, 123

5.2 WiMAX Transmitter & Channel

The WiMAX (802.16-2004) transmitted signal's parameters are: Frequency Band- 2GHz, OFDM carriers - 256, Adaptive Modulation -QPSK, 16QAM, 64QAM, Duplexing TDD and Channel Bandwidth 3.5MHz. After these signals crossing noisy channel (Rayleigh and Gaussian Noise), and applying a multipath Rayleigh fading channel model for complex signals, a Bouncy Detector (BD) or Hop Rate Detector is used to differentiate between the shape of these received signals.

5.3 Signals at Detector

The signal present at the BD output is a time domain signal which contains only noise components when no FH signal is present at the input of the detector. But when an FH signal is resent, the signal at the output will contain an additive sinusoidal component with frequency equal to that of the hop rate of the FH signal. The power spectrum of this signal will, therefore, contain a spectral line at the hop rate. The spectral line is a line which indicates a particular frequency in the frequency spectrum which denotes the presence of an additive sinusoidal component in the signal with the corresponding spectrum.

So the received GSM –FH signal has its own shape. But the case is different in another input signals like WiMAX, where the data and its carrier frequency are fixed in band and couldn't be appear in the two BPFs. So BD gives different shape for GSM and WiMAX signals.

6. The Result and Discussion

By noticing the output of the BDs in time domain, the detection and differentiation between FH-GSM and WiMAX signals can be achieved easily. Where each detected signal has its own shape and it is differs from the other (they don't look alike). Figures (5, 6) show the output of BDs at different parameter values like: hopping rate in FH-GSM and OFDM- cyclic prefix in WiMAX but in ideal case i.e. without noise. Where the hopping rate is 100 hop/sec in GSM signal, OFDM cyclic prefix is 1/8 in WiMAX signal and 200 hop/sec in GSM signal with 1/16 cyclic prefix in OFDM WiMAX respectively. We can notice that the envelope shape for each recovered signal is remaining same with slightly small difference when the parameter values are changed. Figures (7- 9) illustrate the shape of the two signals in time domain also but with different cases of signal to noise ratio (SNR) (-10, 0 and 10 dB) and different parameter values (hop rate is 100, 200 and 500 hop/sec in FH-GSM) and (cyclic prefix 1/8, 1/16 and 1/32 in WiMAX) respectivly. The effect of increasing noise power is appeared only in the amplitude of FH-GSM signal and in the tail of the WiMAX signal but it still easy to differentiate between the shapes of these signals. The possibility of error happened in differentiation it will be zero percent.

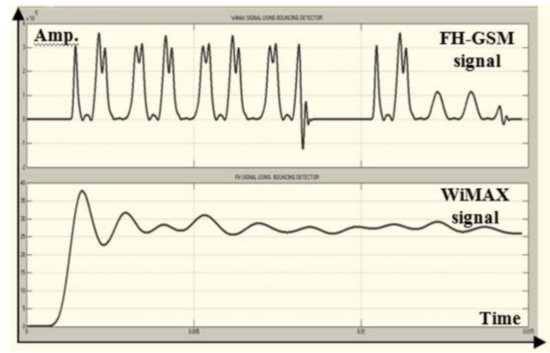

Fig. 5 Signals without Noise, 100hop/s for FH-GSM and 1/ 8cyclic prefix for WiMAX

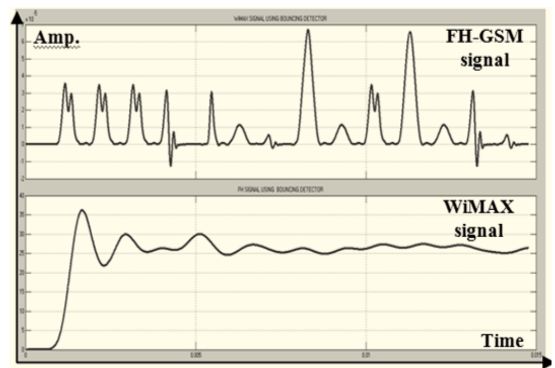

Fig. 6 Signals without Noise, 200hop/s for FH-GSM and 1/ 16 cyclic prefix for WiMAX

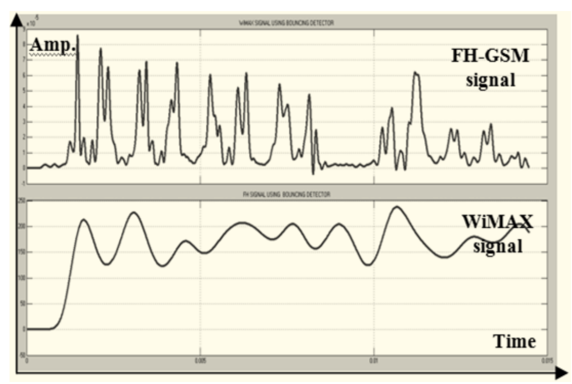

Fig. 7 Signals with SNR= -10 dB, 100hop/s for FH-GSM and 1/8 cyclic prefix for WiMAX

7. Conclusion

In recent years, the exponential growth of wireless communication technologies has forced the emerging diverse technologies, e.g.; wireless cellular networks, WLANs (Wireless Local Area Networks), WWANs (Wireless Wide Area Networks) etc. to coexist This new trend, also referred as the next generation networks, aims that all the wireless technologies work together in order to provide QoS supported and cost efficient services for mobile users at anywhere and anytime.

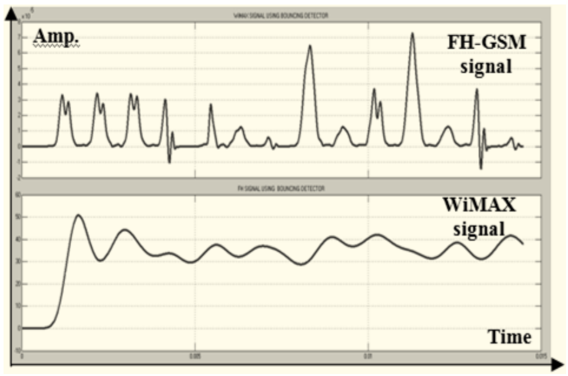

Fig. 8 Signals with SNR = 0 dB, 200hop/s for FH-GSM and 1/16 cyclic prefix for WiMAX

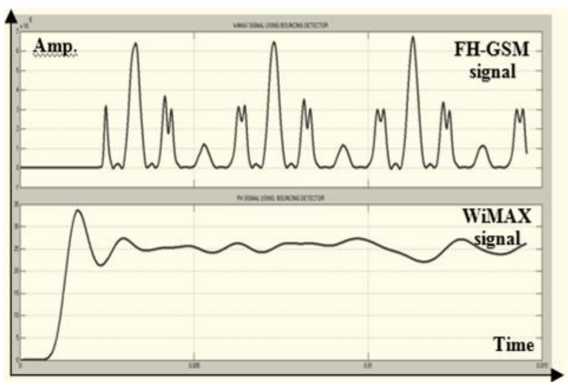

Fig. 9 Signals with SNR =10 dB, 500hop/s for FH-GSM and 1/32 cyclic prefix for WiMAX

So Coordination carried out between public mobile networks and GSM operators shows that there exist remedies to differentiate them when deployed in adjacent frequencies and in geographical close vicinity. Expanding the function of HRD for differentiation and discrimination between GSM and WiMAX signal is very useful. Matlab software has been used to simulate the two transmitters and the noisy channel (Multipath Rayleigh fading channel plus AWGN channel). The Bouncy Detector's output shows that, it can work to differentiate between FH-GSM and WiMAX signals accurately with negligible error even in low SNR value. This is a big advantage of BD along with its simplicity over conventional methods (matched filter detector, energy detector and feature detector), which suffers from many problems like design complexity, threshold level value and false alarm probability in high noise level.

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