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The Most Possible Scheme of Joint Service Detection for the Next Wireless Communication Technologies

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Abstrak

Era komunikasi wireless setelah generasi ketiga (3G) akan semakin beragam yang terdiri dari beberapa teknologi radio akses yang perlu dipadukan ke dalam sebuah multimode terminal. Berkaitan dengan hal tersebut, paper ini memperkenalkan sebuah sistem deteksi layanan bersama untuk teknologi komunikasi wireless masa depan yaitu Long Term Evolution (LTE), WiMAX atau IEEE 802.16, dan Wireless Local Area Network (WLAN) atau IEEE 802.11. Teknik deteksi bersama ini dilakukan pada lapisan fisik sebagai salah satu kemampuan multimode terminal tanpa memperdulikan layanan kerjasama jaringan yang sudah ada.Kami telah melakukan investigasi pada sinyal-sinyal preamble dan sinkronisasi sebagai indikator adanya layanan sebagai pengganti teknik deteksi frequency pembawa. Untuk mendeteksi sinyal-sinyal ini, kami mengusulkan suatu sistem deteksi pada kawasan waktu yang terdiri auto-korelasi, kros-korelasi, dan sebuah penghitung periode puncak. Berdasarkan kompleksitasnya, paper ini mengusulkan sebuah skema yang paling mungkin dengan kompleksitas yang lebih rendah dibandingkan dengan implementasi detektor dengan kros-korelasi. Lebih lanjut, hasil simulasi fixed-point menunjukkan bahwa rancangan yang diusulkan telah memenuhi nilai sensitivitas minimum yang disyaratkan di masing-masing standar.

Kata kunci: *service detection, LTE, IEEE 802.11, IEEE 802.16, multimode terminal*

Abstract

The era of beyond third generation wireless communication is highly heterogeneous in that it comprises several radio access technologies that need to be joined into a single multimode terminal. In this respect, this paper introduces a common service recognition system for the next wireless communication technologies i.e. Long Term Evolution (LTE), WiMAX or IEEE 802.16, and Wireless Local Area Network (WLAN) or IEEE 802.11.It is done in physical layer as one of multimode terminal ability regardless network cooperation existence. We investigation the preamble and synchronization signals as indicators of the available services instead of carrier frequency detection. To detect these signals, we proposed a time domain detection system consisting of auto-correlation, cross-correlation, and a peak period detection. Based on complexity analysis, this paper proposes the most possible scheme with lower complexity than cross-correlation implementation. Moreover, the fixed point simulation results show that the proposed system satisfies the minimum receiver sensitivity requirements that specified in the standards.

Keywords: *service detection, LTE, IEEE 802.11, IEEE 802.16, multimode terminal*

1. Introduction

The wireless technologies can be classified into three main categories: the mobile cellular network technologies (3G and 4G), the wireless local area network technologies (e.g.WiFi) and the wireless metropolitan area network technologies, such as Digital Video Broadcasting and WiMAX [1]. In the future, wireless technology is designed to be an evolution of mobile communication systems aiming at the provision of highly sophisticated services, that it comprises several radio access technologies that need to be made to cooperate with each other [2], [3].

Regarding heterogeneous mix of standards in the terminal side, Gelabert et. al. [4] indicates that multi-mode terminal availability should be considered when designing common radio resource management strategies in heterogeneous wireless access networks. However those techniques are done in case there is cooperation or supporting procedure with each

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other. Therefore, we introduce a multi-mode terminal ability in term of some services detection regardless they support each other or not. In this respect, the physical layer of mobile terminal must be able to handle various communications standards that generally different chip/sample/symbol rates are specified in different standards. The main concept is combining two or more hardware circuits into single system that the common hardware blocks are reused or shared and thus a multi-mode receiver can be implemented with reduced hardware expense [5-8].

There are three general steps in physical layer of multimode terminal. First, just after the mobile station/terminals turned on, it searches the available service cells around it. From the recognized service cell, the most appropriate service is chosen based on a certain algorithm or user can choose freely. In the third step, the mobile station/terminal soon configures itself to become a mobile device that appropriate with the selected standard, then it can process the received packets from the certain service cell.

In order to recognize the available service cells, mobile station needs to perform ”cell search procedure” that consists of frequency scanning, timing synchronization, and cell’s parameters identification [9–12]. Each standard uses different carrier frequency that needs to be detected within frequency scanning. Even though the terminal could store the carrier frequencies information for each standard in its memory, therefore it might use as indicator to recognize the available services, each country might have different radio spectrum regulation and management. Moreover, the regulations might be changed in the future that cause modification in the terminal is necessary. Therefore, we introduce service recognition through appropriate signals that broadcast by base stations. The research was focused on the appropriate signals involved in timing synchronization of three standards, i.e. 3GPP-LTE, IEEE 802.11,and IEEE 802.16.

To aid cell search procedure, base station always transmits known signal in the entire its service area. It is provided by either preamble such as in 802.11 and 802.16, or synchronization signal such as in LTE. Correlation function is a commonly used scheme to recognize them in either the frequency domain or time domain. Some researchers have investigated the preambles and synchronization signals detection for timing synchronization in different standards separately. Tsai and Zhang [13] proposed auto and cross correlation combination to perform time and frequency synchronization for 3GPP LTE. However, Manolakis et.al. [14] and Tannoet. al. [11], [15] introduced frequency domain cross-correlation for synchronization and cell search in LTE. Salbiyono and Adiono[16]reported symmetric based auto-correlation function to detect IEEE 802.16e preambles. Su and Zhang [17] proposed cell search algorithm based on cross-correlation function. For 802.11a WLAN, Manusaniet. al. [18] proposed time synchronization using conjugate symmetry property of long preamble to reduce computational complexity. Further, we consider those schemes in order to develop a common recognition system for five standards with a low hardware complexity.

2. Preambles and Synchronization Signals Patterns

2.1. 3GPP LTE Synchronization Signal

LTE has primary and secondary synchronization channel, P-SCH and S-SCH respectively. S-SCH is no longer discussed due to P-SCH existence is enough to represent LTE service cells availability. P-SCH, used for 5 ms timing synchronization, are generated from a frequency-domain Zadoff-Chu sequences [19]according to

$$d_u(n) = \begin{cases} e^{-j\frac{\pi u n(n+1)}{63}}, & n = 0,1,\cdots,30 \\ e^{-j\frac{\pi u(n+1)(n+2)}{63}}, & n = 31,32,\cdots,61 \end{cases} \qquad (1)$$

where the Zadoff-Chu root sequence index (u) is 25, 29, or34depends on physical layer identity.

Based on Eq.1, we can derive all possibilities of primary synchronization signal as shown in Figure1. Note that these figures are in frequency domain which horizontal axis expresses n and vertical axis belongs to $d_u(n)$.

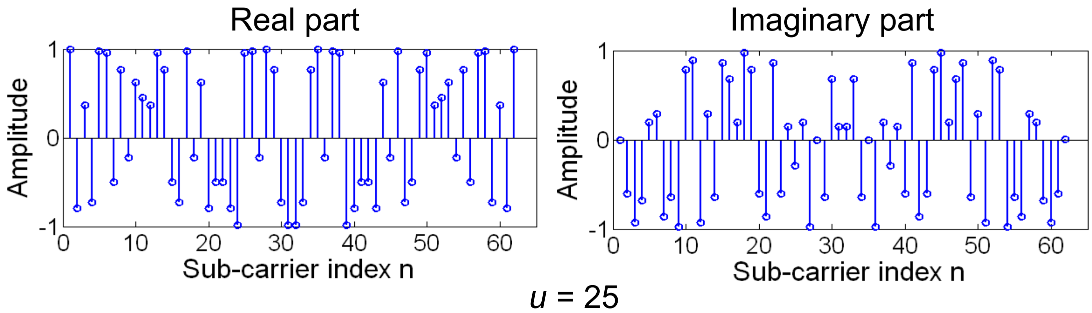
As mentioned in [19], the sequence $d_u(n)$ shall be mapped to the resource elements with frequency-domain index k and time-domain index l, according to

$$a_{k,l} = d(n), \qquad n = 0,1,\ldots,61 \tag{2}$$

$$k = n - 31 + \frac{N_{RB}^{DL}\ N_{sc}^{RB}}{2} \tag{3}$$

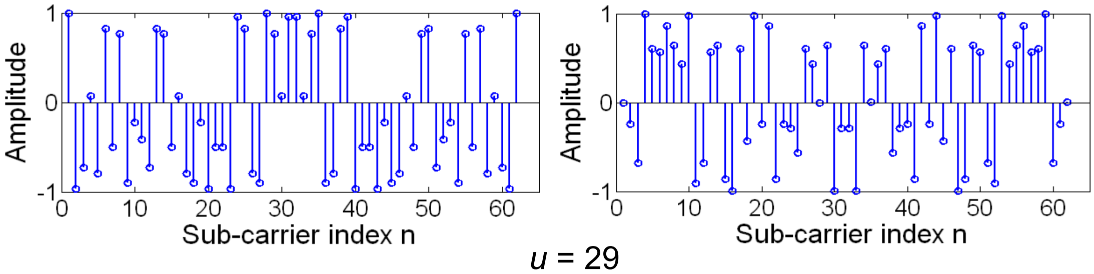
where N_{RB}^{DL} is downlink bandwidth configuration, and N_{sc}^{RB} is resource block size in the frequency domain.

Resource elements (k, l) for n =−5,−4, · · · ,−1, 62, 63, · · · , 66 are reserved and not used for transmission of the primary synchronization signal. Furthermore, we can derive time domain signal by mapping only primary synchronization signal based on Eq.2 and Eq.3in 2048 point IFFT as shown in Figure2.

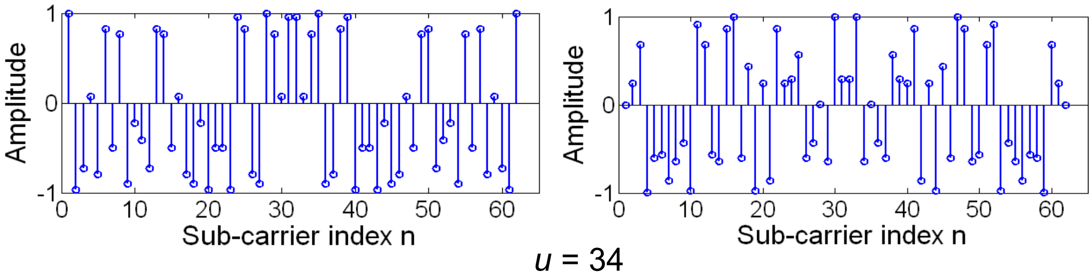

Real part

Imaginary part

u = 25



u = 29



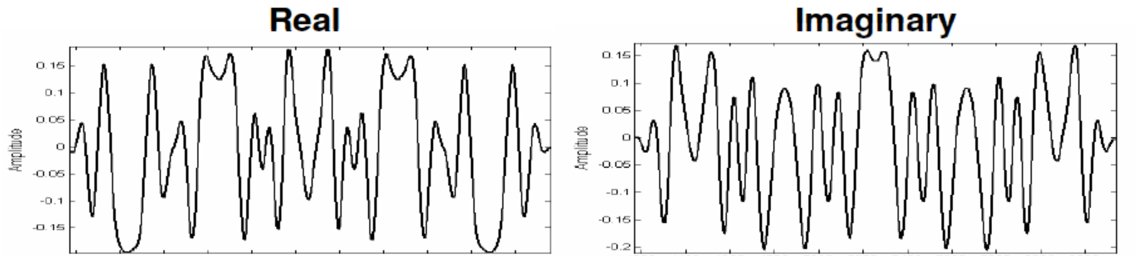
u = 34

Figure 1. Primary synchronization signals of LTE in frequency domain

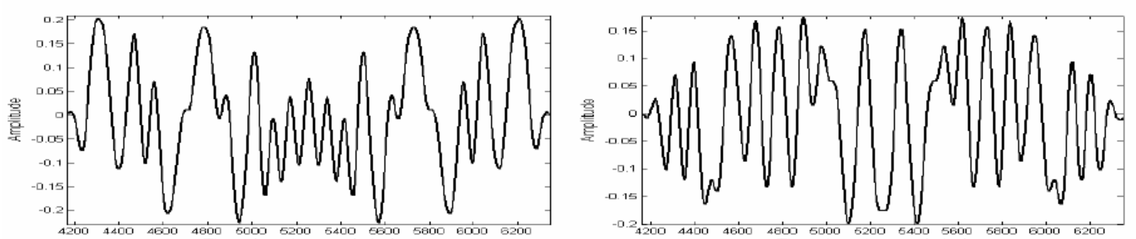
P-SCH detection in LTE is not easy because of the frequency domain term. Moreover, the spectrum flexibility in LTE makes P-SCH detection more complex. However, P-SCH is transmitted only in the central part of the overall transmission band of the cell, i.e. the constant bandwidth of 1.25 MHz, regardless of the overall transmission bandwidth of the cell [20]. Therefore, we should focus on some sub carriers around the central of bandwidth to detect P-SCH.

2.2. IEEE 802.16 d/e Preamble Signal

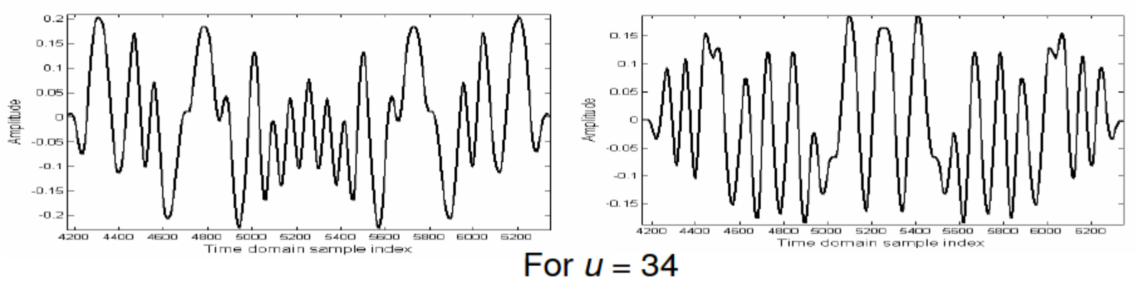
There are four types of PHY Layer mentioned in IEEE802.16 standard; wireless MAN single carrier, wireless MAN single carrier access, wireless MAN OFDM, and wireless MAN OFDMA [30]. In this paper, we discuss the OFDM and OFDMA schemes only.



For $u = 25$



For $u = 29$



For $u = 34$

Figure 2. Primary synchronization signals of LTE in time domain

2.2.1. OFDM Scheme

In this scheme, preamble always exists in the start of a packet. Therefore, preamble becomes the most effective signal in term of service recognition. As mentioned in [21],the frequency domain sequences for all full bandwidth preambles in OFDM mode are derived from the sequence:

$$\begin{aligned}P_{ALL}(-100,100) = [&D,D,C,A,D,D,B,D,D,D,D,A,C,A,A,C,A,C,C,D,B,D,D,C,\\ &A,D,D,B,D,D,D,A,C,A,A,C,A,C,C,D,B,D,D,C,A,D,D,B,\\ &D,D,D,A,C,A,A,C,A,C,C,D,B,A,A,D,B,A,A,C,A,A,A,B,\\ &D,B,B,D,B,D,D,A,C,C,C,B,D,C,C,A,C,C,C,D,B,D,D,B,\\ &D,B,B,C,A,0,C,A,B,B,C,A,A,A,C,A,D,D,D,B,B,B,B,D,\\ &C,C,B,D,A,A,B,D,D,D,B,D,C,C,C,A,A,A,A,C,B,B,A,C,\\ &D,D,A,C,C,C,A,C,B,B,B,D,D,D,D,B,A,A,C,A,B,B,C,A,\\ &A,A,C,A,D,D,D,B,B,B,B,D,C,C,D,B,C,C,D,B,B,B,D,B,\\ &A,A,A,C,C,C,C,A,D,D\,]\end{aligned} \tag{4}$$

where $A = 1 + j$; $B = -1 + j$; $C = -1 – j$; $D = 1 – j$.

Preamble in OFDM mode consists of two consecutive OFDM symbols with4 MHz sampling rate. The first symbol in time domain has four repetitions of 64-sample fragment denoted $\mathrm{P}_{4\times 64}$ preceded by a cyclic prefix (CP). The frequency domain sequence for $P_{4x64}$is defined by:

$$P_{4\times64(k)} = \begin{cases}\sqrt{2}\cdot\sqrt{2}\cdot conj\big(P_{ALL}(k)\big)\ k(mod4) = 0 \\ 0 \qquad\qquad others\end{cases} \tag{5}$$

The second symbol in time domain is composed of two repetitions of a 128-samplefragment denoted P_{EVEN}. In frequency domain it is defined by:

$$P_{EVEN} = \begin{cases}\sqrt{2}\cdot conj\big(P_{ALL}(k)\big)\ k(mod2) = 0 \\ 0 \qquad\qquad others\end{cases} \tag{6}$$

The preamble signals generated based on Eq.(4), (5), and (6) are given in Figure 3.

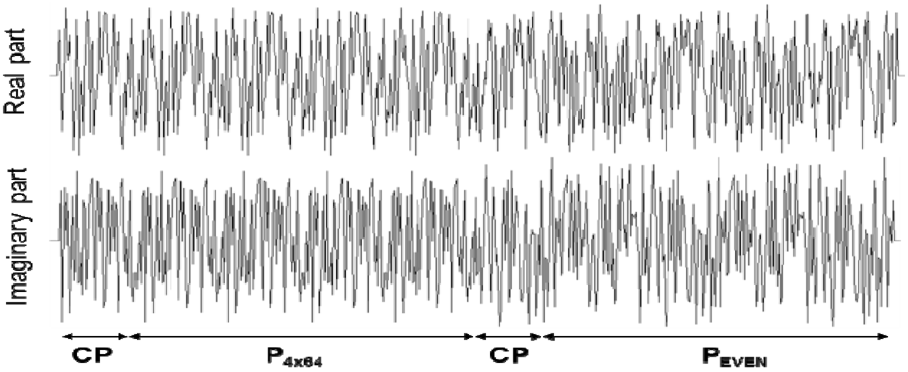


Figure 3. Preamble signal of IEEE 802.16 OFDM

2.2.2. OFDMA Scheme

In OFDMA scheme, there are three types of preamble carrier sets[21], those are defined by allocation of different subcarriers for each one of them and expressed as

$$PreambleCarrierSet_n = n + 3k \tag{7}$$

where $PreambleCarrierSet_n$ specifies all subcarriers allocated to the specific preamble, n is the number of the preamble carrier-set indexed 0,1,2, and k is a running index0,1,…567.

Each segment uses one type of preamble out of the three sets in 22.4 MHz sampling rate. Each of differentFFT sizes has 114 different pseudo number (PN) series patterns as defined in[21]. This means the receiver should consider 456 preamble patterns for four different FFT schemes when performing preamble detection. However, preambles are modulated using a boostedBPSK modulation, therefore, the output samples satisfy complex conjugate symmetry property [22] i.e. symmetry for I-part and anti-symmetry for Q-part as shown in Figure 4.

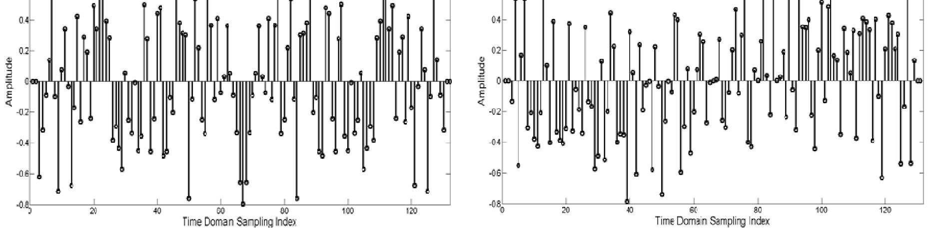


Figure 4. An example of 802.16 OFDMA preamble for index = 43, IDcell= 13, and segmen = 1

2.3. IEEE 802.11 Preamble Signal

There are three modulation schemes provided in IEEE802.11 [23] i.e. frequency-hopping spread spectrum (FHSS), direct sequence spread spectrum (DSSS), and orthogonal frequency division multiplexing (OFDM). This paper is limited on OFDM scheme since it is widely implemented in wireless LAN.

All OFDM packets in wireless LAN are preceded by preamble that consists of 10 short and two long training symbols. A short training symbol consists of 12 subcarriers, which are modulated by the elements of the sequence, S, given by:

$$S_{-26,26} = \sqrt{\frac{13}{6}} \times [0,0,k,0,0,0,-k,0,0,0,k,0,0,0,-k,0,0,0,-k,0,0,0,k,0,0,0,\\ 0,0,0,0,-k,0,0,0,-k,0,0,0,k,0,0,0,k,0,0,0,k,0,0,0,k,0,0] \tag{8}$$

where $k = 1 + j$.

The multiplication by a factor of $\sqrt{\frac{13}{6}}$is in order to normalize the average power of theresulting OFDM symbol, which utilizes 12 out of 52 subcarriers. A long training symbol consists of 53 subcarriers (including a zero value at dc), which are modulated by the elements of the sequence L, given by:

$$L_{-26,26} = [1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,\\ 0,1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,\\ -1,1,1,1,1] \tag{9}$$

Based on Eq. (8) and (9), IEEE 802.11 OFDM preambles are shown in Figure5.

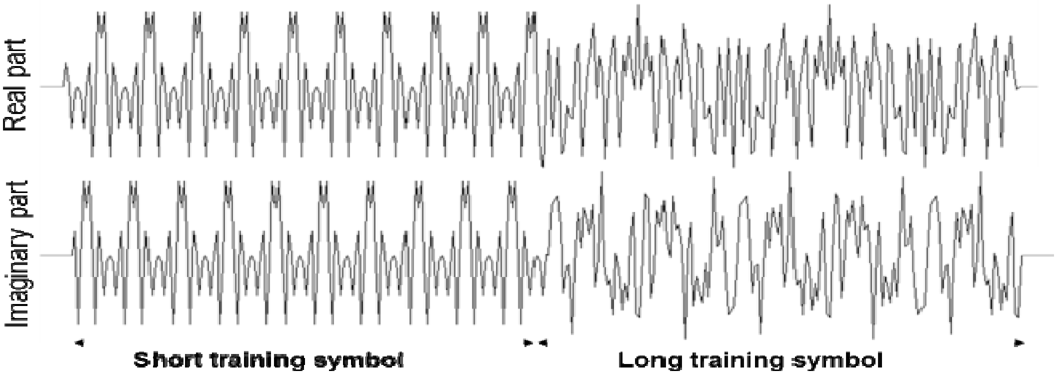


Figure 5. IEEE 802.11 OFDM preamble signal

3. The Proposed Detection Technique

All services, LTE, 802.11, and 802.16, generate their synchronization and preamble signals in frequency domain. Hence, there are two options i.e. time domain and frequency domain detections. Some analyses to decide one of them are given below. As the cell search procedure is carried out without the channel compensation, in most of the multipath fading channel environments, the frequency domain cross-correlation is liable to get corrupted[17]. Thus, from this point of view there is no advantage to treat preamble or synchronization signals in frequency domain. Since the signals are transmitted in time domain, FFT processes should be involved to get frequency domain signals. However, there are some disadvantages when FFT block is employed. First, FFTinvolvement means complexity increment that comes fromFFT itself, and packet symbol synchronization prior to FFTprocessing. Second, FFT involvement means latency increment. The total latency is consisted of OFDM symbol synchronization latency and FFT process latency. From those reasons, time domain detection is better to be introduced since FFT block is no longer involved.

Correlation function is commonly used to recognize preamble signals. It is used to describe the degree of relationship between two signals. Symmetric based auto-correlation, repetition based auto-correlation, and cross-correlation are the possible schemes to be employed for preamble and synchronization signals recognition. Their properties for N received signal are decrypted in Table 1.

Table 1. Auto-correlation and cross-correlation properties

Properties	Cross-correlation	Symmetric based Auto-correlation	Repetition based Auto-correlation
Signal length	N	N	N
Signal pattern	A-B-C-D	A-B-B-A	A-B-A-B
Number of tap	N	N/2	N/2
Number of register	N	N	N
Number of multiplier	4N	N	N
Number of adder	4N-1	N-1	N-1

Furthermore, the correlation schemes suitability to detect LTE synchronization signal, IEEE 802.16 and IEEE 802.11 preambles as shown in Table 2.

Table 2. Correlation schemes compatibility

Services	Cross-correlation	Symmetric based Auto-correlation	Repetition based Auto-correlation
LTE	Yes	Yes	No
802.11 OFDM	Yes	Yes	Yes
802.16 OFDM	Yes	No	Yes
802.16 OFDMA	Yes	Yes	No

Based on Table 2, 802.16 OFDMA preamble can be recognized using either symmetrical based auto-correlation or cross-correlation. However, we propose symmetric based auto-correlation because 2048 tap cross-correlation to detect IEEE 802.16 OFDMA preamble requires high computation resources than 1024 tap symmetric based auto-correlation. Regarding LTE synchronization signal recognition, we also propose symmetric base auto-correlation because of the complexity. Further, computation resource sharing is involved for both LTE and IEEE 802.16 OFDMA service detection in order to reduce the complexity.

Even though 802.11 OFDM have three options and 802.16 OFDM have two options, the repetition based auto-correlation has aplateau in timing metric, which causes large variance result [24]. Therefore, cross-correlation should be considered at the same time to get better peak result.

Based on previous discussion, we derive that the most possible scheme of joint service detection architecture for LTE, IEEE 802.16 and IEEE 802.11 consists of symmetric based auto-correlation, repetition based auto-correlation, and cross-correlation. However, an unexpected signal that has an instantaneous property similar with preambles or synchronization signals we want to detect could make misinterpretation. Therefore, we introduce peak period detection. It is the time distance between one peak (as the result of signal correlation detection) to the next peak. Since either synchronization or preamble signals are transmitted during the constant period, the peak will appear within a constant period as well. Further, we divide our proposed system into three groups denoted as process 1 up to process 3 as shown in Figure 6.

Process 1 consist only the symmetric based auto-correlation. Symmetric-based auto-correlation is developed to recognize 802.16 OFDMA preambles as well as LTE synchronization signals. The number of tap to recognize LTE synchronization signal can be reduced from 2048 to 256 due to the synchronization signal occupies the center of 1.25 MHz out of 20 MHz total bandwidth. However, the maximum IFFT size for 802.16 OFDMA is 2048, thus2048 tap symmetric-based auto-correlation should be considered. For 2048 tap symmetric-based auto-correlation, 2048 multipliers and 2047 adders are required. However, the complexity is still smaller than cross correlation implementation.

Process 2 consists of repetition based auto-correlation and cross-correlation in order to detect 802.16 OFDM and802.11 OFDM services. Since each of them has two adjacent signals that should be detected, four signal patterns are stored in ROM and used in the cross-correlation processing. We introduce computation sharing in 64 tap cross-correlation architecture. However, to select one out of two adjacent signals that should be proceeded in cross-correlation, we employ 16 tap (for IEEE 802.11) or 64 tap (for IEEE 802.16 OFDM) repetition based auto-correlation to generate enable signal. Therefore, cross-correlation totally employs 256 multipliers and 255 adders, while repetition-based auto-correlations need 80 multipliers and 78 adders.

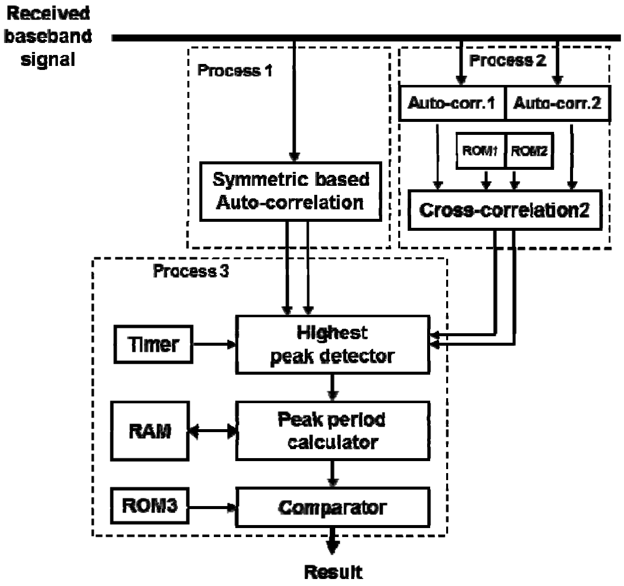


Figure 6. Block diagram of the proposed scheme

Process 3 consists of highest peak detector, peak period calculator and comparator. The main purpose of this block is to calculate time distance between two adjacent highest peaks in such of time frame. This process consists of four parallel processes that independent for each standard. The main idea is stated as follows; every a peak detected for each standard, the peak amplitude as well as time index from timer will be stored in a register. The amplitudes then compared to the previous highest peak. Every one cycle of time frame, the time index of the highest peak is picked up and compared with the time index of the previous highest peak in previous time frame that stored in the other register. The result, i.e. the difference time index, is compared with the peak period data stored in ROM. If the comparison result is satisfied, it means that the service available. From the complexity point of view, process 3 are employing three adder in two comparators and a timer.

4. Results and Analysis

Based on previous discussion, the computation resources required by the proposed scheme are 2384 multipliers and 2383 adders. Note that we only consider multipliers and adders since they are the dominant factors in computation complexity calculation. In order to clarify the effect of proposed system, we take conventional scheme as comparer. We assume the conventional scheme uses cross-correlation for all standards separately. Thus, LTE, IEEE 802.16 OFDM, IEEE 802.16 OFDMA, and IEEE 802.11 employ 256, 128, 2048, and 64 tap cross correlations, respectively. By considering cross-correlation complexity, totally 9984 multipliers and 9980 adders are employed. Hence, the complexity of the proposed scheme is around 1/4 of the conventional scheme.

Furthermore, we develop the proposed system and perform some fixed point simulation schemes. Note that, we assume that the carrier frequency synchronization is ideal. The simulation results and the analysis are given below.

The first simulation focus on LTE and 802.16 OFDMA services recognition performance. Figure 7 and Figure 8 show the recognition performance in various channel models and SNR for LTE and IEEE 802.16 OFDMA services available respectively. The figures show the worst detection probability for LTE occurred in ITU pedestrian B channel while the worst probability for 802.16 OFDMA is in EPA channel.

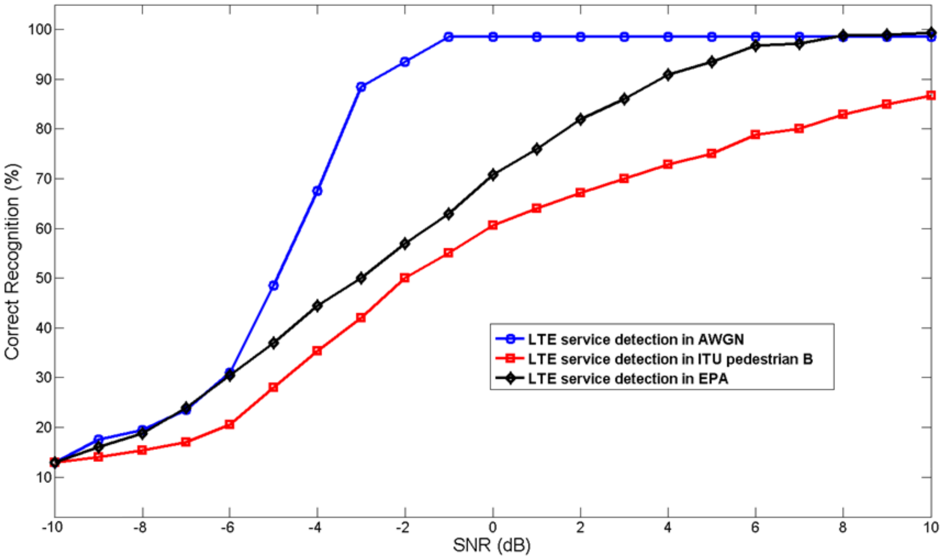


Figure 7. Proposed scheme performance for LTE service recognition

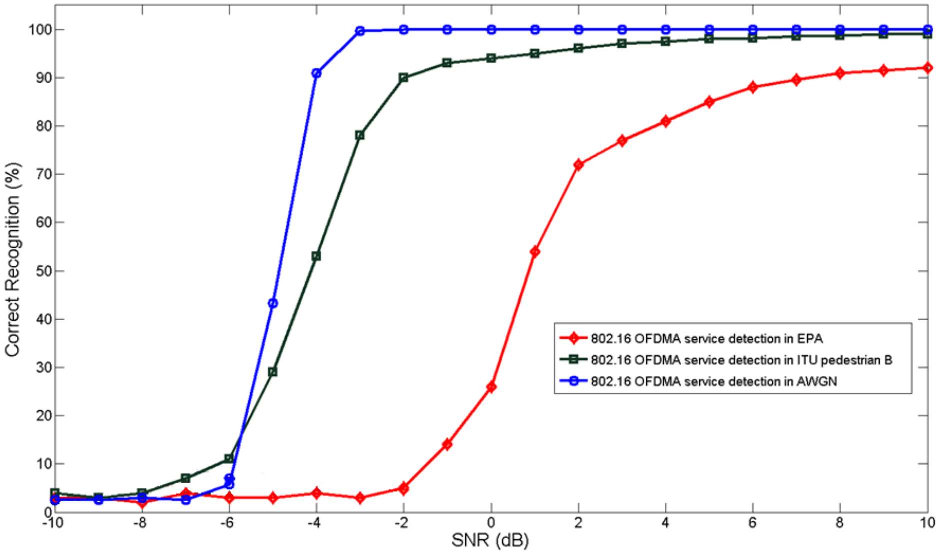


Figure 8. Proposed scheme performance for IEEE 802.16 OFDMA service recognition

Based on [21], for IEEE 802.16 OFDMA, by taking the worst case for QPSK modulation, the BER measured after FEC shall be less than 10^{-6} at SNR 5 dB in AWGN channel. Suppose the length of packet is 1000 byte, the packet error rate is approximately $10^{-6} \times 8000 = 8 \times 10^{-3}$. However, the simulation result shows that 100% of IEEE 802.16 OFDMA service cells can be recognized in -2 dB of AWGN channel. It means that the proposed system fulfill the IEEE 802.16 OFDMA detection requirement.

For LTE case, the throughput shall be at least 95% of the maximum throughput with receiver sensitivity -91dBm on 20 MHz bandwidth [25]. Assuming 10dB noise figure, antenna gain 0 dB, and minimum equivalent input noise for a receiver at 300K is -174 dBm/Hz, the minimum SNR requirement is $-91 - (-174 + 10\log(20 \times 10^6) + 10) = 0$ dB on AWGN channel. However, figure 7 shows a better result, thus the proposed system passed the minimum requirement.

Service recognitions for 802.16 OFDM and 802.11 OFDM are done in process 2. Since both of them are dedicated for non-mobile devices, the performance drops when either ITU pedestrian B or EPA is employed as shown in Figure 9 and Figure 10. However, in AWGN channel condition, the proposed scheme gives better performance for 802.16 OFDM detection than 802.11OFDM detection due to the wider correlation window size.

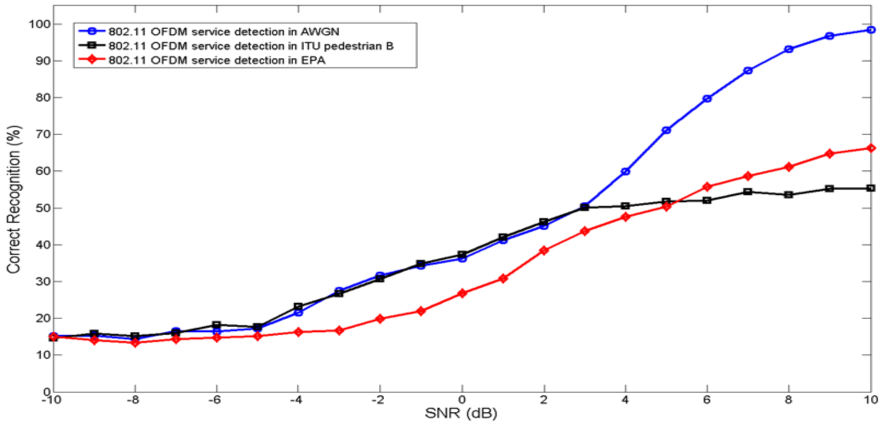


Figure 9. Proposed scheme performance for IEEE 802.11 OFDM service recognition

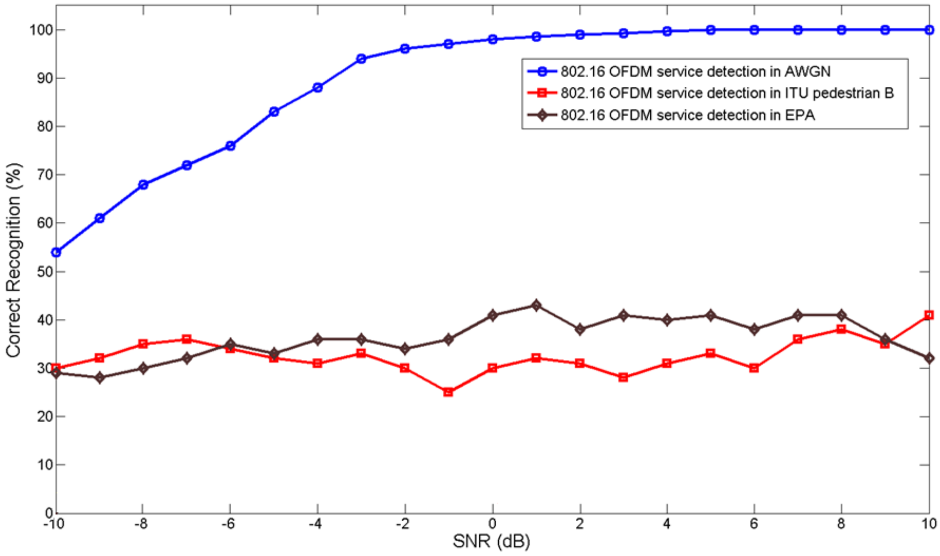


Figure 10. Proposed scheme performance for IEEE 802.16 OFDM service recognition

The receiver minimum sensitivity for IEEE 802.11 OFDM as mentioned in [23] is -82dBm with FER shall be less than 10%on AWGN channel. Considering 10dB noise figure and20MHz bandwidth, the minimum requirement to recognize IEEE 802.11 OFDM is $-82-(-174+10\ \log(20\times10^{6})+10) = 9$ dB. In Figure 10,it is clear that receiver minimum sensitivity requirement is satisfied. However, for 802.16 OFDM, the BER measured after FEC shall be less than 10^{-6} at SNR = 3dB [21]. Assuming the length of packet is 1000 byte, the packet error rate is approximately$10^{-6}\times8000 = 8\times10^{-3}$. However, the proposed system gives detection probability 99.7% at SNR equal to 3dB that means it satisfies the minimum requirement.

4. Conclusion

In this paper, we have proposed the system to recognize 3GPP LTE, IEEE 802.16 and802.11 OFDM service cells as one of multi-mode terminal abilities. We have proposed the detection on physical layer instead of frequency carrier and network layer in order to avoid any modification due to radio spectrum regulation and network management adjustment.

We investigated the preamble and synchronization signals as indicators of service cells availability. Based on these investigations, we developed low complexity system that consists of auto-correlation, cross-correlation, and peak period detection. The complexity was predicted1/4of the employing cross-correlation for all standards.

In this paper we have done fixed point simulations as well. The simulations have been done for AWGN, ITU pedestrian B, and EPA channel models. The simulation results show that the proposed system has met minimum requirements with some given boundaries based on minimum receiver sensitivity in AWGN channel.

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