Investigation of Mobility Supports for Smart-Secured-Seamless (SSS) Public Transportation in Kuala-Lumpur Based on TV White Space

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***Abstract*— The future smart public transport infrastructure is emerging as a complex web, where fine-grained monitoring of all transportation systems via wireless communication will be made possible. Inadvertently, resulting in Smart-Secured-Seamless (SSS) public transportation network infrastructure. Kuala-Lumpur (KL), the capital city of Malaysia is endowed with a network of well-developed and articulated public transportation system. However, there is no hotspot while in or around the KL public transport hubs to facilitate Smart-Secured-Seamless connectivity either for the management or for the commuters. Leading to relying on commercial Internet providers for internet access. In order to solve this problem, we are proposing using Television White Space (TVWS) technology to provide connectivity to all bus/train public transport hubs in Kuala-Lumpur and environs. Based on our framework, we draw conclusion regarding the feasibility and commercial importance of SSS public transport framework, and identify some of the remaining technical challenges. We presented simulation based on Clarke-Gans channel model to study Doppler shift effects. Results, indicate that there is no remarkable performance difference between 802.22 TVWS wireless standard and 802.16e WiMAX, which is the closest wireless standard to 802.22. Hence, offering TVWS as the preferred and alternative wireless standard for intelligent transport system in Malaysia.**

Keywords*— *TVWS, mobility model, smart transport system, large scale fading.

I. Introduction

The recent spectrum measurement conducted in Kuala-Lumpur is in conformity with the other global results; that spectrum in the upper VHF and UHF bands allocated for TV broadcast are currently underutilized as depicted in Fig. 1 [1]. The temporary vacant TV channels are referred as Television White Space (TVWS). TVWS technology is the first real world deployment of Cognitive Radio (CR) technology. Some wireless standards have indicated an interest to offer wireless access to the consumer markets using TVWS and subsequently, have defined the PHY and MAC layers parameters for the ensuing standards. These wireless standards include; IEEE 802.22 - Wireless Regional Area Networks (WRANs), 802.11af Wireless Local Area Networks (WLANs), and IEEE 802.15.4 - the Smart Utility Networks (SUN) [2]. TVWS technology is spurred by the underutilization of TV spectrum in most rural areas as well as the digital switchover. By 2015, Malaysia will be expected to join the league of countries that have moved from analogue TV transmission to digital television transmission [3].

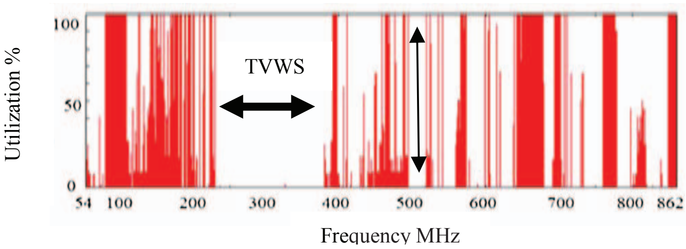

Fig.1 Spectrum Utilization Measurement for KL [1]

In the future, it is envisaged that the Internet of Things (IoT) infrastructure will be strongly integrated with the public transport system. Thus, creating an intelligent public transport ecosystem in which information and content savvy citizens are always connected. Before now, the smart city concept consist of service-based Internet of Energy (IoE) and water utilities. While neglecting the public transport system. Because public transportation plays a crucial role in our lives, there is a need to include smart public transportation in the smart city concept. The expansion of utility networks driven by Internet and management of the available wireless spectrum present a set of unique challenges that requires a proactive and attainable solutions. In order to solve the challenges, we are proposing Smart-Secured-Seamless (SSS) public transportation using TVWS. Till now, there is no real deployment of CR network in transportation system. As the first step towards the deployment intelligent transport system on TVWS, we developed a Secured- Smart - Seamless public transportation framework in TVWS. It is anticipated that current IEEE 802.22 specifications will undergo some modifications to overcome challenges of vehicular mobility. The main contributions of this paper are highlighted as: (i) SSS framework based on TVWS CR technology; (ii) Derivations of public transport traffic models in TVWS cell planning; (iii) Future challenges in mobility supports for TVWS. The layout of this paper is as follows: the objectives of the paper is described in Section II. Related studies are critically reviewed in Section III. Methodology is considered in Section IV. Results and discussions are presented in Section V. Finally, conclusions are drawn in Section VI.

II. OBJECTIVES

Cognitive radio network as implemented in TVWS can serve as a platform to improve such end-to-end objectives of broadband access, wireless resource management, QoS, security, access control and throughput. This paper focuses on deploying IEEE 802.22-based wireless CR network to enhance the Security, Smart, Seamless (SSS) transportation system in Kuala-Lumpur as shown in Fig.2 below.

Security – operator and enforcer focused. Imagine using TVWS technology to provide real time surveillance camera functionality in public bus and train system. The bus/train system will be fitted with micro-camera.

Seamless - clients focused. Seamless is the direct desire for commuters to connect to the internet while in public transport entities. Consequently, there is a need for up/down converter because smart phones, laptops operates in 1.8 and 2.45-2.50 GHz respectively. While, TVWS operates in the UHF (300 – 1000 MHz) bands. The up/down conversion will be done by Consumer Premises Equipment (CPE) which is connected to a router. Hence, the interference concerns with Primary Users (PUs) are under control.

Smart – operator focused. There is also the possibility of infusion of telematics into SSS model powered by TVWS technology for train/bus tracking and real time update.

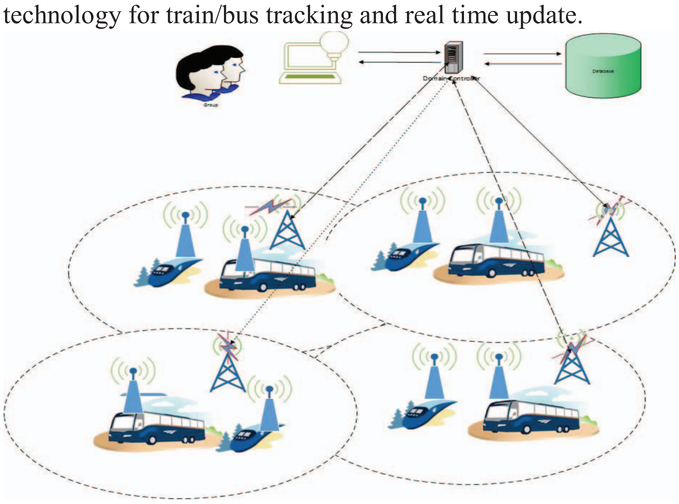

Fig.2 Conceptual Smart-Seamless-Security Public Transportation using TVWS for Kuala-Lumpur

III. RELATED STUDIES

The need for improvement on the current derogatory public transport ecosystem while enhancing operational efficiency has led to new Intelligent Transport System (ITS) driven on numerous readily available wireless communications technologies. Many research papers and proposals have been presented on how to achieve wireless deployment on public transportation system. In [4], Dedicated Short-Range Communications (DSRC) operating on 5.9 GHz band with 75 MHz bandwidth was proposed. The author presented a tutorial overview of DSRC applications and assessed IEEE 802.11 PHY and MAC layer characteristics necessary for actualization of technology. The discussed technology is not viable for the present day intelligent public transportation system based on the transmitting frequency range of the underlying radio technology. Furthermore, DSRC technology was designed based on Mobile (multihop) Ad hoc Networks (MANETs).

An improved version of MANET technology was proposed in the form of mesh technology [5]. Mesh topology comprises of MANET and infrastructural networks each assisting in the end-to-end wireless connectivity. Thereby, extending the range and QoS of the system. However, the mesh network topology as advocated above may give rise to high packet loss because of the changing functionality of the nodes at a given time. Hence, making it unsuitable for seamless public intelligent transport system. Other challenges facing the IEEE 1609 Wireless Access in Vehicular Environments (WAVE) standard family has been presented [6]. LTE technology has also been proposed for vehicular transportation [7]. However, in-terms of coverage range, TVWS provides better range.

The IEEE 802.16 and 802.20 have been proposed to solve the problem of “first-mile/last-mile” connection in WMANs [8]. Nevertheless, 802.16 baseline standard leans more towards line-of-sight (LOS) communications and operates in the ISM bands. Though, a recent evolution in the access scheme can suppress the LOS challenges via MIMO antenna technology. The standard has limited tolerance capability for multipath interference. IEEE 802.20 standard reinforces ubiquitous mobile broadband wireless access in a cellular architecture, supporting the mesh and NLOS communications for indoor and outdoor scenarios. While IEEE 802.16e supports vehicular mobility of 120 km/h [10], 802.20 supports 350 km/h [6]. All the aforementioned wireless standards operate in the spectrum of the license bands. Consequently, deploying SSS model to the existing infrastructure will increase, the already over-utilization wireless spectrum issues. Secondly, the radio links are of short range resulting in higher infrastructural outlays. Thirdly, short waves are easily attenuated by manmade and natural obstacles presenting unreliable links. In summary, TVWS presents a suitable alternative as the wireless channel for intelligent public transportation system in-terms of radio wave quality and infrastructural roll-out cost.

IV. METHODOLOGY

Intelligent transport system (ITS) architecture serves as a platform for the much anticipated smart transportation ecosystem. In considering smart public transport system, we have moved the public transport system from a black box infrastructure to an interconnected active entities capable of providing broadband connectivity to public transport users. In realizing the above goal, a wireless standard, which has the following characteristics will adequately serve; (i) support multiuser through OFDMA resource block allocation scheme; (ii) supports variable modulation schemes-QPSK, 16-QAM and 64-QAM; (iii) longer range radio waves capable of achieving further distance in a cluttered environments and minimal infrastructural roll-out cost; (iv) non auctioned spectrum bands.

The primal goal of any technology is that, it meets some need in the best way possible taking least cost. Talking about needs, there is a huge demand for broadband connectivity in all the public transport systems due to growing demand on mobility. The field of CR is constantly drawing research attention due to their wide range of technological applications and the technical challenges they exhibit. CR has received enough theoretical research papers and has witnessed a stall in applications. The Smart-Secured-Seamless (SSS) public transportation network as proposed for Kuala-Lumpur Malaysia commences with a detailed analysis of the components blocks that make up the SSS framework.

Blocks of A, B and E in the framework are envisioned not to constitute severe technical challenges because they can be leveraged on. While, block C and D will constitute some challenges based on the fact there is no existing technology to rely on. In designing this framework as shown in Fig.3, the two possible mobility scenarios; (i) nomadic – (no mobility) and (ii) vehicular usage were captured. Nomadic mobility model analyse the data-rate at the bus/train stations. While, vehicular is for bus/train in motion. This section tries to explain each of the blocks and how it contribute to the overall functionality.

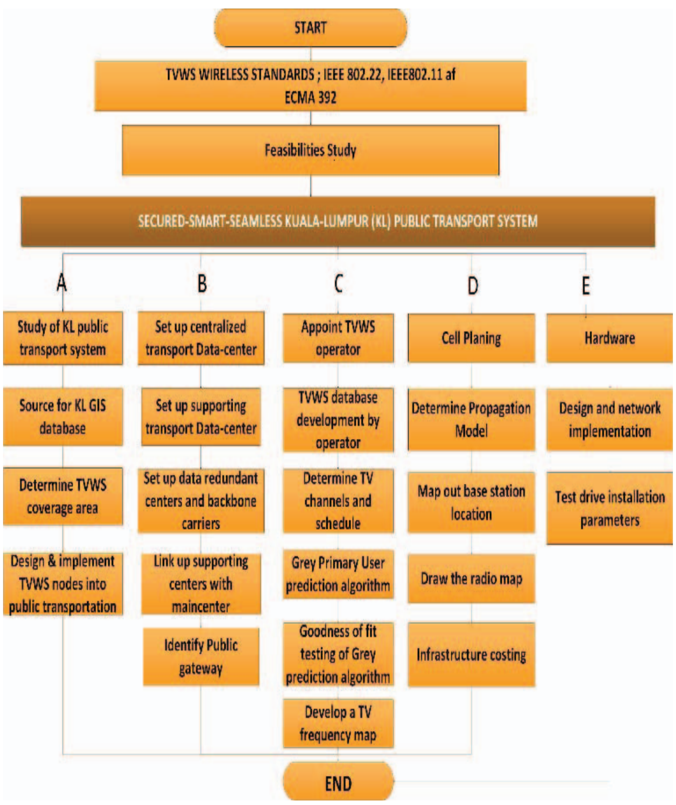

Fig. 3 Smart-Seamless-Security Public Transportation Framework.

As a budding technology, it is expected to face some regulatory and technical challenges and hence, the following assumptions becomes necessary;

Assumption 1: The policy engine of spectrum sharing is not prohibited in Malaysia.

Assumption 2: The TVWS spectrum will be exclusively reserved for public transportation.

Assumption 3: Spectrum sensing will be leveraged by Geo-location TVWS database for accurate and overhead spectrum channel availability information.

Assumption 4: TVWS cell planning will leverage on the matured cellular planning for mobile communication.

Assumption 5: Data security will be through the upper layer security of the OSI model and data protocols currently implemented by non-cognitive networks.

A. *Physical Infrastructural Analysis*

In block A of the framework, a detailed analysis of the road and train network of KL will be needed. The essence of this is to have knowledge of the city traffic pattern so as to determine the appropriate cell radius architecture. The traffic herein is of types stated in (1), and (2) respectively;

$$\gamma_{route} = \frac{\varphi}{\alpha} \quad (1)$$

where γ_{route} is the vehicular traffic intensity per unit time, φ is the length of a cross section of a route and α is the number of moving trains/bus in a given time. As expected, trains operate in a single carrier mode in which only one train is travelling or at most two in a given route so it is expected to have lesser value than bus. However, train carries more passengers than bus so a scaling up parameter σ will be needed for train transportation. Hence for train, (1) is further expanded into;

$$\gamma_{route}^{train} = \sigma \frac{\varphi}{\alpha} \quad (2)$$

Recall that our proposal is for both modes herein trains/buses in motion as well as train/bus stations. The traffic pattern γ for train/bus stations is as follows;

$$\gamma_{stat} = \frac{\rho}{\beta} \quad (3)$$

γ_{stat} denotes bus/train station, ρ is the area occupied by a given train/bus station and β is the number of passengers currently in the train/bus hub stations. This traffic pattern analysis will enhance the estimate achievable data-rate Mb/s and determine appropriate mobility models to use. Thus, decreasing outage probability and increase end-to-end QoS. Equations (1) and (2) facilitates the cell planner to determine the appropriate routing protocols either to go for Distance Vector (DV) or for Hop Counts (HC) metrics. Since our goal to ensure a minimum threshold of QoS for end-to-end users for both modes of public transport scenario, the extension of scenario is important. The number of people in the train/bus stations and the number of train/bus on a given route is dynamic. Hence, we extend traffic pattern to capture the mean time passengers wait in the bus/train stations, Ψ, and is given as;

$$\psi = \frac{d\gamma}{dt} \tag{4}$$

The effective traffic pattern γ^{eff} for bus/train station is derived in (5);

$$\gamma_{sta}^{eff} = \psi \cdot \gamma_{sta} \tag{5}$$

That of γ_{route} train and bus is given as;

$$\gamma_{route}^{eff} = \sigma . \gamma_{route} . \psi \quad \sigma = 1; \forall_{bus}^{\gamma} \tag{6}$$

In order to ensure a base throughput of data-rate of 23 Mbits/s and decreases the outage probability, a parameter known as of Cell Spectral Efficiency, SE_{CELL} is defined. The SE_{CELL} is the number of correctly received bits delivered to the upper layers of the MAC Service Access Points (MAC SAP) over a certain period of time, divided by channel bandwidth divided by the number of cells. The SE_{CELL} of each user in γ_{route}^{eff} is given as;

$$SE_{CELL,route} = \frac{\sum_{i=1}^{N} \gamma_{route}^{eff}}{TBM} \text{ bits/sec/Hz/cell} \tag{7}$$

$i = \{1,2,\ldots.N\}$ denoting no bus/ train sharing a channel B and each TV channel bandwidth is 6 MHz because that's the assigned bandwidth for TV channels (region specific), M denotes TVWS cells, and T the time in over which the data bits were received. That of the bus/train station γ_{sta}^{eff} is stated as;

$$SE_{CELL,sta} = \frac{\sum_{i=1}^{N} \gamma_{stat}^{eff}}{TBM} \text{ bits/sec/Hz/cell} \tag{8}$$

In considering cell edge user spectral efficiency, a 5% point cumulative distribution function of the normalized bus/train station δ_i throughput is considered because of the desire to minimize margin gap in actual deployment. The normalized δ_i stat is given as;

$$\delta_{i,stat} = \frac{\gamma_{stat,i}^{eff}}{T_i B} \tag{9}$$

Where T_i is the correctly received bit by each user in particular train/bus station in $\gamma_{stat,i}^{eff}$. While normalized δ_i for train/bus station is given as;

$$\delta_{i,stat} = \frac{\gamma_{route,i}^{eff}}{T_i B} \tag{10}$$

Based on the analysis of block A, a detailed decision is made on where the hotspots are likely to be situated in the road/train networks based on traffic per density. Furthermore, the data results from block A will be crucial in making decision either to adopt uniform cell radius or location specific cell radius. The GIS of KL will be needed to map out incumbent TV transmitter locations so as to preserve their protected service contour. The importance of this will be useful during cell planning and TV base station site location. A design parameter of choosing appropriate cell topology is considered here.

B. Enabling Technologies

The enabling infrastructure for successful implementation of the intelligent SSS public transportation framework is captured in block B. Studies conducted confirmed that there is a decrease in the TVWSs as we move from rural to semi-urban areas and urban areas [1]. This will have an over-bearing effect on the number and position of data centers. The urban cities may need HetNet backup when there is huge constraints on spectrum availability. It is expected that the urban centers will have more data centers taking cognizance that they are the commercial hub of the country. The public gateways are also located in the urban centers. This means that data from the rural and semi-rural areas will be routed through the public gateways located in the urban centers. In [9], channel bandwidth backup reservation mode from the spectrum management entities has been proposed. The technical details and modalities of this is yet to be explored.

C. TVWS Database

Spectrum sensing is an integral part of cognitive radio but till now, no reliable sensing modules have been developed as an experimental test conducted by Motorola and Microsoft in 2008 failed to protect the incumbent [10]. Consequently, the FCC amended the rules that sensing modules are not mandatory for the time being. Thus, certifying geo-location as the only reliable TVWS spectrum information module. Effectively, leaving sensing-only terminal for future research to enhance sensing module reliability [11]. Due to the difficulties associated with sensing process and to ensure and guarantee strict protection of the incumbent transmitters, geo-location database has been attracting attention. There has been open invitation from the FCC to corporations with technical capability seeking to be designated as White Space Database (WSDB) Managers. The WSDB providers can decide what type of access mode is favourable to them. The access modes are proprietary and open access mode. In proprietary mode, the clients are required to pay fees to the providers to acquire the TVWS database information. While, in open access scheme, TVWS database services are downloaded over the Internet.

D. Propagation Model

In other to decouple the complexity associated with TVWS cell planning, our approach involves two different propagation models. The need for the two different propagation models arose based on the need to protect the incumbent by not locating TVWS BS at the incumbent protected service contours. ITU-R P.1546 propagation model is the preferential model to estimate the protected areas of TV transmitters [12]. For the Cell planning, Hata model for urban, suburban and open areas seems appropriate because it has been used to predict the received signal level at large distances, from several to hundreds of kilometers [13]. However, Hata model does not adequately capture all the possible propagation parameters associated with such environment. Hence, the need for combinatory propagation model of COST Hata pathloss model, which is intended for large cells, with BS being placed higher than the surrounding rooftops. To factor in Rayleigh fading, COST Hata model is combined with Clarke-Gans model, which has been extended to support 2048 subcarriers in IEEE 802.22 [14]. The power delay spread are captured using the International Telecommunication Union (ITU) power delay model of Vehicular A at 60 km/h , which deem appropriate herein, considering the larger cells and high BS antenna height of TVWS. Secondly, since this model is for public transportation, the average speed of most bus/train in KL is within 60 km/h speed range.

V. RESULTS AND DISCUSSIONS

In this section, we evaluate the plausibility of our proposal. Our discussion is primarily on a comparison between 802.16e WiMAX and TVWS standard of 802.22. Since our model framework is towards the network backbone for transportation, Doppler shift is an appropriate performance parameter for discussion.

A.. Vehicular Mobility Supports and Doppler shift

The SSS public transportation framework is design based on the premise that IEEE 802.22 will support vehicular mobility. The closest standard to 802.22 which supports vehicular mobility is 802.16e (WiMAX). Therefore, it becomes imperative to analyze the features of 802.16e, which supports mobility. For 802.16e to support mobility, there were slight amendment in the PHY and MAC layers of the base 802.16 standard. The amendment was to enhance performance of power restricted mobile device. A detailed PHY layer comparison between 802.22 and 802.16 e are given in the Table I below;

TABLE I

Selected PHY Layer Similarity between 802.22 [3] and 802.16e [12]

Air Interface	802.22 -TVWS	802.16 e-WiMAX
PHY Profile	OFDMA, 6 MHz	OFDMA, 5 MHz
FFT Mode	2048	512
Sampling Frequency (MHz)	6.9	5.6
Subcarrier Spacing (KHz)	3.3	10.9
Useful Symbol Time (1/Δf) (µsec)	298.7	91.4
Max CP Time (µsec)	74.7	11.4

As can be seen from Table I, there is no remarkable difference between 802.16e and 802.22. Mobile WiMAX have a subcarrier spacing of 10.94 kHz, which is compatible with vehicular mobility up to 120 km/h when operating in 3.5 GHz. 802.22 has a subcarrier spacing of 3.3 kHz, meaning that it can support vehicular mobility although at a lower vehicular speed. The mobility performance is further enhanced when TVWS operating frequency in the upper UHF bands. Furthermore, we extend the analysis on Doppler shift effect using Clarke Gans model at 60 km/h. Based on simulated result as shown in Figs. 4, 5, 6, 7, there was no remarkable phase and magnitude difference for the maximum Doppler shift. Comparing the magnitude of WiMAX-802.16e and TVWS, the histogram has same dome shape thus exhibiting similar characterizations.

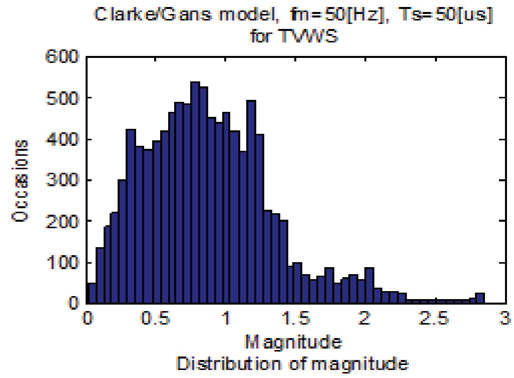

Fig. 4. Doppler shift analysis of TVWS at 60 km/h in Mag

The dove-tail region of WiMAX flats out towards the end because of shorter wave-length, while much longer for TVWS because of the frequency of operation as indicated. This parameter will not have an adverse effect on TVWS because the burst allocation compensates for the delay in propagation under varying distance. Furthermore, the inclusion of bursts in the frame architecture of 802.22 enhances mobility

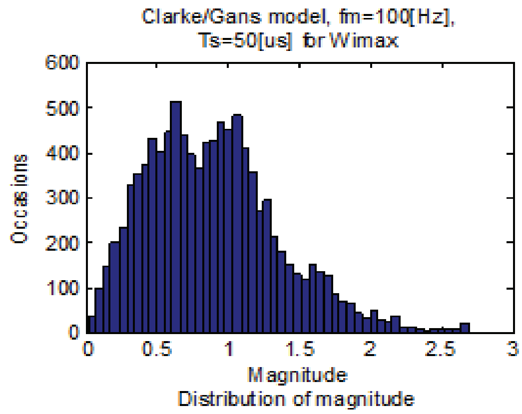

Fig. 5. Doppler shift analysis of WiMAX at 60 km/h in Mag

Evidently, there is a remarkable change in phase distribution of phase between WiMAX and TVWS. The phase change is a function of operating frequency and by extension, wavelength.

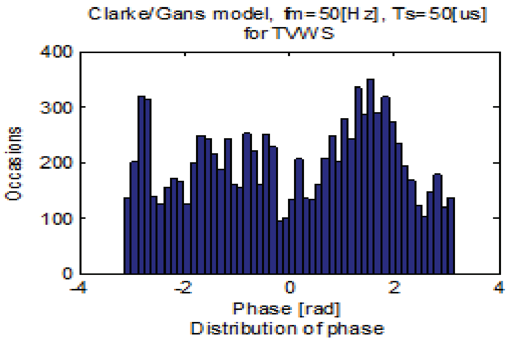

Fig. 6. Doppler shift analysis of TVWS at 60 km/h in Phase

This feature can be corrected by application of appropriate signal techniques to correct any abnormalities. Besides, since the CPE in TVWS uses directional antenna, phase shift will not be a problem.

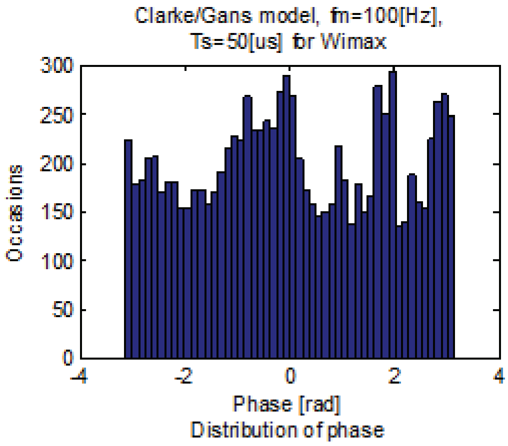

Fig. 7. Doppler shift analysis of WiMAX at 60 km/h in Phase

VI. Concluding Remarks

TVWS PHY layer features consistently support the appropriate technology for intelligent public transportation system. Many proposals and policy papers have been presented on spectrum re-farming and deployment of TVWS spectrum into other applications such as; smart grid, WLAN, emergency and public safety etc. None, has been suggested on smart public transportation system driven by wireless backbone. The Smart-Secured-Seamless (SSS) public transportation conceptual framework for Kuala-Lumpur using TV White Space (TVWS) as proposed is implementable despite some challenges.

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