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TV White Space Network Provisioning with Directional and Omni-directional Terminal Antennas

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Abstract—Operating at ultra-high frequency (UHF), TV white space (TVWS) can achieve long-distance communication and good in-building penetration, and has attracted increasing attention of regulators, researchers and stakeholders. This paper explores the potential of TVWS for network provisioning within a cluster of buildings, through a succession of tests. Different transmission distances, from 10m to over 120m, and through multiple layers of walls as well as complex transmission environment imposed by other factors like office and construction facilities, are considered. Further, a compact ultra-wide band (UWB) printed monopole antenna is designed for the client white space terminal, and compared with a commercial directional UHF antenna on the same client. Measurement results show that the in-house compact antenna achieves fast network speed and a high signal-to-interference-plus-noise ratio (SINR), and it is orientation independent.

Index Terms—TV White Space, UHF, UWB, Antenna, Network Provisioning

I. INTRODUCTION

TV white space (TVWS) is unused spectrum in the TV bands, the amount of which has been greatly increased by the freeing up of spectrum caused by the digital dividend transiting terrestrial television broadcasting from analogue to digital. TVWS can potentially be used for applications such as smart metering, network provisioning, and transport and logistics, among many others. The secondary use of TVWS through associated geolocation database-based frameworks has taken some of its first regulatory steps and seen the first deployments of White Space Devices (WSDs) in the US, driven by the Federal Communications Commission (FCC) [1], [2]. Further experiments with TVWS supported by Microsoft, Google and others have been piloted in Africa [3], [4], and elsewhere.

In the UK, TVWS is regulated by Ofcom, the independent regulator and competition authority for the UK communication industries. WSDs are operating at TVWS in the ultra-high frequency (UHF) TV band (470-790MHz), which is divided into forty 8MHz channels, from channel 21 to channel 60. Following rules enshrined in the ETSI 301 598 Harmonized European Standard [5], trials within a large pilot of WSDs obtain TVWS network access on one or multiple idle channels, while ensuring no harmful interference is caused to licensed services in the TV bands. In [6], the availability and capacity able to be achieved in TVWS scenarios in the UK are measured and discussed with commercial white space system and antennas. Performances of long-distance outdoor point-to-point transmissions as well as indoor transmissions are also evaluated with bulky log-periodic antennas at the client

white space terminal. As of January 2016, Ofcom has made regulations which enable licence exempt use of white space devices as the first approach to implement cognitive radio in reality from regulatory point of view [7].

Covering 320MHz of spectrum in the UK, or 296MHz if the reserved channel for shared PMSE usage and the banned usage of the lower-most and upper-most TV channels are taken into account, UHF TV spectrum has over 50% bandwidth, and its one or multiple idle channels are allocated to TVWS services dynamically through TVWS geo-location database [8], [9], [10]. WSDs are required to be able to operate at the entire UHF TV spectrum through geo-location database, spectrum sensing or its combination [11], [12]. Hence, compact and low profile ultra-wide band antennas to cover the UHF TV band are essential. However, lengths of common antennas are around a half-wavelength of their resonant frequency, and as a result antennas working at 500MHz are about 30cm long. Moreover, antennas with a fractional bandwidth of more than 50% are referred to as ultra-wideband antennas (UWB) [13], which require even larger sizes and high profiles.

In this paper, a network working on TVWS is built, and a low-profile, compact and light antenna is designed for WSDs as clients. With fixed base station and transmitting power, network performance is tested and evaluated by moving clients to different locations. Furthermore, the proposed antenna and a commercial antenna are connected to the client at each location to compare their performance.

The rest of this paper is organized as follows. The TV white space testing system and two client antennas are introduced, and seven typical wireless links are chosen in Section II. Section III presents measurement results with different terminal antennas at the client in different locations within the building and between buildings. Conclusions are drawn in Section IV.

II. SYSTEM DESCRIPTION

The measurement set-up is based on the RuralConnect TV White Space Radio provided by Carlson Wireless Technologies [14]. This radio follows a Carlson proprietary standard, which is close to IEEE 802.22 in characteristics, to provide wireless network access using TVWS. The set-up of both TVWS base station and clients is described as follows.

A. TVWS Base station:

The base station Fig. 1 is placed at the third floor of the EE building in the Mile End campus of Queen Mary University of London (QMUL), and is connected to the Ethernet. Radio

TABLE I: Comparison of commercial log-periodic antenna and self-designed printed monopole

Antenna Type	Dimension (cm^3)	Weight (Kg)	Frequency Range (MHz)	Beam Width (3dB down)	Polarity	Peak Gain (dBi)	Antenna Connector
Log-periodic	$38.1 \times 35.56 \times 10.1$	0.91	470-786	35° vertical 30° horizontal	Linear	9	75Ω F-type
Printed monopole	$23.1 \times 3.5 \times 0.8$	0.02	460-905	80° vertical Omnidirectional horizontally	Linear	1.68	50 Ω SMA (a 50Ω SMA to 75Ω F-type impedance converter is used for connection)

Fig. 1: Sector antenna connected to base station

(a) (b)

Fig. 2: (a) log-periodic antenna and (b) printed monopole connected to client

frequency transmit power of this device is set to 23dBm. Signals are transmitted from a directional sector antenna whose gain is 11dBi and its feeding cable has 1dBi loss, and hence the EIRP is 33dBm. Position and direction of the base station antenna is fixed, and its maximum radiation direction is set towards the northwest direction and 33.25m above mean sea level.

Fig. 3: Radiation patterns of both log-periodic antenna [15] and printed monopole on (a) elevation plane and (b) azimuth plane.

TABLE II: Variances of SINRs acquired when client antennas facing at different directions

Links	Uplink (dB) (Log-periodic antenna)	Uplink (dB) (Printed monopole)	Downlink (dB) (Log-periodic antenna)	Downlink (dB) (Printed monopole)
Link1	1.699	0.987	2.151	0.662
Link2	2.112	1.350	1.890	0.700
Link3	1.802	1.325	0.795	1.122
Link4	3.871	1.527	2.939	1.365
Link5	1.307	1.792	2.834	1.427
Link6	4.386	1.945	7.024	2.063
Link7	2.050	1.823	2.155	0.427

TABLE III: Variances of SINRs acquired when client antennas facing at different directions

Links	Downlink Speed (Mbps) (Log-periodic Antenna)	Uplink Speed (Mbps) (Log-periodic Antenna)	Downlink Speed (Mbps) (Printed monopole)	Uplink Speed (Mbps) (Printed monopole)
Link1	6.706	1.821	7.941	2.011
Link2	7.844	2.151	9.265	2.126
Link3	10.597	2.742	10.07	3.081
Link4	6.527	3.596	7.703	3.05
Link5	4.293	1.599	3.492	1.322
Link6	3.675	1.761	4.723	1.833
Link7	7.401	3.754	9.466	3.560

B. TVWS Client:

RuralConnect clients use external antennas. A very compact printed monopole covering the whole UHF TV band is pro-

Fig. 4: Floor plans of EE building (composed of Section I, Section II and Section III), People's Palace, CS building and ITL building. Ground floor is in white, first floor is in orange, second floor is in yellow and third floor is in green.

posed, fabricated and measured by QMUL. For comparison, a commercial log-periodic antenna [15] is also connected to the client during measurement. The set-up of the client connected with the printed monopole and log-periodic antenna is shown in Fig. 2. Properties and parameters of the two antennas are listed in Table I. According to Table I, the printed monopole is 211.6 times smaller and 45.5 times lighter than the commercial antenna. Owing to its large size, metallic structure and narrow beamwidth, the maximum gain of the periodic antenna is 7.32dBi higher than the printed monopole. The radiation patterns on elevation and azimuth planes of both the commercial periodic antenna and the printed monopole are given in Fig. 3, from which it can be seen that having an omnidirectional radiation pattern, the printed monopole should see less signal strength variation when pointing in different directions. Moreover, the 2dBi gain realised by the printed monopole is efficient for clients in this TVWS radio communication system, and this is verified in results of a series of tests given in Section IV. A laptop is connected to the client to monitor realised wireless network speeds as shown in Fig. 2.

III. TESTING LOCATION SELECTION

Tests are conducted among buildings of Electron Engineering (EE), Computer Science (CS), Peoples Palace and Informatics Teaching Laboratory (ITL) in the Mile End campus of QMUL. EE building has three sections and Section I and Section II are connected through a corridor at the 2nd floor. The base station is fixed at Room 358 in the EE building as depicted in Fig. 4. Standing next to base station, the sector antenna points at northwest and is 15m higher than the ground floor. During transmissions signals undergo reflection, fading and multipath interference due to people, office facilities, walls, trees and etc. Hence, moving client to different locations, seven links represents different communication scenarios are tested.

- Link1: Client is in Room 353 and is 12.65m away from base station. In the shortest transmission path, signals go through 3 walls to reach client.
- Link2: Client moves to electronic lab which is just one floor below Room 358.
- Link3: Client is in EE hub on the 2nd floor in Section I of EE building, and the distance between client and base station is 37.25m. Although they are located at different

Fig. 5: Link SINRs with client antenna facing at different directions. SINR of uplink signal is noted by 'o' and that of downlink is noted by '+'. Blue symbols stand for SINR acquired using log-periodic antenna at the client and red symbols are for using printed monopole.

sections of EE building, Room 358 can be seen from window of EE hub.

- Link4: Client is three layers lower than base station when being placed at the ground floor of Section I of EE building. There are several walls and distance of 47.33m between client and base station. However, space between Section II of EE building and Peoples Palace is under construction, and signals from base station have to go through much metal construction site equipment to arrive client.
- Link5: In the fifth link, client is on the first floor of Peoples Palace. Distance between client and base station

is 56.77m. In addition to the construction yard, signal transmitted to and from the client situating in a corner can also be affected by the two walls surround it.

- Link6: CS hub is also on the third floor and it is 78.19m away from Room 358. CS building is very complicated and there are many offices between client and base station. Besides, tall trees are outside CS building, and the Bancroft Road between EE and CS buildings is busy.
- Link7: This link is 127.5m and goes through Room 358, Room 357, edge of Section III of EE building and a busy road. Client is one floor lower than the base station. Nevertheless, ITL building has French window.

IV. MEASUREMENT RESULTS AND ANALYSIS

In the Mile End campus of QMUL, there is an ongoing construction between EE building and Peoples Palace and another next to Section II of EE building as illustrated in Fig. 4. The log-periodic antenna and printed monopole are connected with client respectively within each link and both of them face southeast, southwest, northeast and northwest in turn. When each antenna facing at one direction, signal-to-interference-plus-noise ratio (SINRs) and speeds of both uplink and downlink are measured four times to remove effects of environment variation during a short period of time. Measurement results with antenna direction being taking into account are plotted in Fig. 5, in which blue symbols stand for SINR acquired using log-periodic antenna at the client, and red symbols for using printed monopole. SINR of uplink signal is noted by 'o' and that of downlink is noted by '+.

- Link1 and 2 are in-section transmissions. Link3 and 4 are in-building but between-section transmissions, and link5, 6 and 7 are between-building transmissions.
- When base station and client are close to each other, strong signals are distributed in the entire environment and according to Fig. 5 (a), (b) and (c), both uplink and downlink SINRs achieved by printed monopole and log-periodic antenna at every direction are high and have similar values.
- Signal strengths in link5 and link6 degrade due to further distance between base station and client and complex transmission environment including increased number of walls, trees, construction and people in common areas as described in III.
- Although having the longest communication distance, signal transmission in link7 is more direct owing to its encountering fewer obstacles. Hence less energy is consumed due to reflection and fading.
- Variances of mean SINRs from four testing results using two antennas pointing at each direction in every link are summarized in Table II. It is clear that printed monopole sees less SINR variation in most scenarios. SINR variations acquired from using printed monopole in downlink of link3 and uplink of link5 are higher than those from log-periodic antenna, which can be resulted from distinct environment change occurring during tests with printed monopole.
- Having lower gain, SINR achieved by using printed monopole is lower than what is achieved by using log-periodic antenna in most cases according to Fig. 5, but

this can be compensated by systematically automatic modulation methods selection and as a result reduce bit error rate. In addition, as illustrated in Fig. 5 (e) and (f) when signal strength is not strong around entire environment where client located, very poor signal reception may arise due to strong coming signals are caught by weak gain direction of the log-periodic antenna.

- Downlink and uplink speeds are given by an online software SPEEDTEST [16], and mean speeds of client antennas facing different directions are summarized in Table III. To reduce error, speed is tested four times when each client antenna facing one direction. Realised speeds obtained from using printed monopole are close and sometimes even faster than those from using log-periodic antenna.
- The Mile End campus of QMUL is covered with WIFI, but when a device is at the same place where client is located in link7, it is easily to lose WIFI signal. However TVWS signals can still be detected according to Fig. 5(e), and uplink and downlink speed is 1.322Mbps and 3.492Mbps respectively if use printed monopole. Therefore it is verified that TVWS signals have stronger competence to bypass obstacles than WIFI signals and a wireless network built on it is more easily to be reachable at corners than a WIFI wireless network.

V. CONCLUSION

This paper has described a series of tests and measurement on a TV white space (TVWS) network. By moving a TVWS client, communication links have involved multiple scenarios including in-building and between-building transmissions with floor level differences from 0 to 4, and signal reflection, fading and multipath interference resulted from walls, people, glasses, office facilities and constructions have been taken into account. Two UHF ultra-wide band (UWB) antennas are connected to the TVWS client separately. One is an in-house developed compact monopole with omnidirectional radiation pattern, and the other is a commercial log-periodic antenna radiating directionally. Link interference-plus-noise ratios (SINRs), SINR variances, average realised speeds with antennas facing different directions are given. Testing results reveal that network established on TVWS is able to travel long distance, skirt obstacles and hence does not require line-of-sight transmission and achieves low energy consumption. Realizing reasonable gain and uniform performances in multiple directions, the printed monopole is orientation independent and takes more advantages than the log-periodic antenna when used for network acquiring among a group of buildings. In addition, since the printed monopole is compact and low profile, it is capable to be integrated into devices like laptops and tablets.

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