COMPARISON OF TDD LTE AND IEEE 802.11AF DEPLOYMENT IN TVWS BAND

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Abstract:
Comparison of TVWS solutions based on TDD LTE and IEEE 802.11af has been presented. It can be concluded that both technologies provide option for deployment in UHF TV band but selection should be made on multiple criteria such as type of end users, required technical parameters and overall price of the deployment. It is shown that proposed solutions could serve for alternative wireless broadband access in developed countries as well for underserved and low income population. It can be concluded that IEEE 802.11af will be superseded by IEEE 1900 standard based solutions in order to improve its' communication and coexistence performances while TDD LTE could be a better solution regarding throughput and costs of deployment if sufficient spectrum is available.

Keywords:
TV white space, TDD long term evolution, broadband wireless access.

1. INTRODUCTION

Affordable ubiquitous nomadic and mobile broadband access has been assumed by end users in many countries. Although wireless broadband access is available, it is often not affordable to all population. Because of that, it is still interesting to investigate technologies and solutions that could be used to provide wireless broadband services to the underserved end users. After years seeing WiMAX as a potential solution for broadband wireless access, even after large scale deployments like the one described in [1], license free bands and secondary use of licensed bands have become more interesting. Two most interesting solutions are time division duplex (TDD) based long term evolution (LTE) [2] and IEEE 802.11af [3] and IEEE 1900 group of standards [4] intended for deployment in frequency bands intended for TV signal terrestrial broadcasting. These solutions have been seen as potential solutions for deployment of wireless networks with large coverage footprint that could serve users both in indoor and outdoor environment. There has been extensive analysis related to 3G and 4G networks [5] performances and some research related to IEEE 802.11af technology [6] and in general technology intended for TV White Space (TVWS) [6, 7]. Nevertheless, direct comparison on multiple criteria has not been performed in order to estimate in what scenarios is each of these technologies a better solution for underserved and low income end users.

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In order to perform such analysis, we have performed simulation analysis of IEEE 802.11af and TDD LTE deployments in the selected London area in order to estimate coverage and throughput but also deployment simplicity and financial requirements. In the Heading II, basic description of aforementioned technologies has been provided stressing the key comparison criteria. In Heading III we describe simulation model and provide results for comparison on TVWS solutions in urban London area. Heading IV is discussing costs requirements related to the used equipment and proposed scenarios while Heading V provides concluding remarks.

2. KEY TECHNICAL AND ECONOMIC PARAMETERS

TVWS band has attracted attention of several research institutions [8, 9] and several equipment manufacturers that offer their solutions. In general, 2 key technologies have arisen as candidates for deployment in TVWS. One is IEEE 802.11af that has been defined as IEEE 802.11 series standard intended for solutions deployed at TV bands and TDD LTE. Each technology provides certain benefits so they should be compared before final selection.

IEEE 802.11af that is superseded by 1900 standard series operates with 6MHz and 8MHz channel bandwidths, which is appropriate for FCC [10, 11] and ETSI TV standards [12-15]. Also, it could be used with bundled TV channels thus allowing operation with 2 neighboring TV channels and theoretically even 4. On the other side, TDD LTE offers operation with different channel bandwidths, starting from 5MHz, over 10MHz and 15MHz to 20MHz. As such, only 5MHz could be used in the case of a single TV channel while others when at least 2 or 3 TV channels are bundled according to ETSI TV channel bandwidth specifications.

Frequency band from 470MHz to 790MHz has been seen as a candidate for deployments of TVWS systems [16]. Thanks to selected frequency band, propagation effects are rather good and much better comparing to previously used 2.5GHz or 3.5GHz used in the case of WiMAX deployed for fixed wireless access. In the existing trials and deployments, LTE based solutions have been deployed in upper part of this band, from 700MHz and above while IEEE802.11af solutions have been deployed in frequencies close to 500MHz. Due to such frequencies selection, in a free space loss environment, IEEE 802.11af would have additional 3-3.5dB in a link budget, comparing to TDD LTE.

Deployment of TVWS systems as secondary users in TV band is very limited due imposed constraints of interference caused to primary (TV) users, [16, 17]. It can be concluded that such deployment, as secondary users in occupied TV channels, with low cost end user equipment is hard to achieve as it might require sensitivity levels as low as -140dBm or - 120dBm [16]. Because of that, it is to expect that TVWS systems will be deployed in areas where certain TV channels are not used by primary users. Digital Dividend II has been specified in the band from 694MHz to 790MHz with intention to make this band available for mobile communication services. Because of that, it can be expected that it will be somewhat easier to find available radio channels in the part of the frequency band below 694MHz. Either it might be during the transmission period while freeing the band from TV broadcasting or after as a part of overall LTE ecosystem. Nevertheless, certain types of deployment such as deployments in underground environment will not impose any limits on frequency bands used.

TVWS devices can provide up to 4W (36dBm) of effective isotropic radiated power (EIRP) with strong intention to limit EIRP to as low as 16dBm, especially in the case of end user portable devices [18] in order to minimize interference towards primary spectrum users. It should be stressed that ETSI [19] has somewhat less restrictive requirements thus enabling more relaxed deployment. Nevertheless, in the case of UK, analysis from OFCOM [20] has shown that implementing lower transmission powers will enable a higher number of TV channels to be available for TVWS systems deployment. In deployment scenarios presented in [20] it is stated that there will be only 28% of locations with 5 TV channels available for TVWS systems deployment while with 25dBm and 20dBm this availability goes up to 77% and 88% and for more restrictive deployments even over 90% of locations.

It is most likely that transmission power will be limited due to regulatory issues and potential interference during the operation. We can say that available transmission power will not be the key parameter for selecting IEEE 802.11af or TDD LTE TVWS equipment for the deployment. Existing IEEE 802.11af equipment usually can have receiver sensitivity level (RSL) close to -102dBm in order to keep connection alive at QPSK. TDD LTE equipment would have the same level and in the case of complex antenna configurations even lower, down to -112dBm. Nevertheless, such low levels are not applicable for end user side, especially if low cost devices are required.

Both IEEE 802.11af and LTE TDD could be defined as broadband wireless technologies. Assuming 6MHz wide

TV channel, commercial IEEE 802.11af based devices could provide throughputs over 30Mb/s in a single 8MHz wide TV channel, Table 1.

Modulation	Code Rate	Data	Pilot	Throughput	
		Subcarriers		CP 4.5µs	CP 2.25µs
BPSK	1/2	108	6	2.4	2.7
QPSK	1/2	108	6	4.8	5.3
QPSK	3/4	108	6	7.2	8
16-QAM	1/2	108	6	9.6	10.7
16-QAM	3/4	108	6	14.4	16
64-QAM	2/3	108	6	19.2	21.3
64-QAM	3/4	108	6	21.6	24
64-QAM	5/6	108	6	24	26.7
256-QAM	3/4	108	6	28.8	32
256-QAM	5/6	108	6	32	35.6

Table 1. Throughput for ieee 802.11af device in 8mhz wide tv channel, [3].

In practical deployments, these throughputs are smaller but still over several megabits per second thus providing broadband access to end users. With multiple channels bundled, IEEE 802.11af can provide throughputs over 50Mb/s and 100Mb/s, which is more than enough for home and business users. LTE TDD can provide similar throughputs at 5MHz wide channel and up to 112Mb/s for 20MHz wide channel assuming Category 3 LTE device. It is clear that both technologies could serve as an alternative broadband technology if enough of spectrum is available.

Standardization of the technology and the equipment is always a pre-requirement for wide adoption of the solution in the market. LTE has been standardized within 3GPP [2] and ETSI [21]. IEEE 802.11af has been standardized within IEEE [22], including technology, coexistence and dynamic spectrum access. IEEE has standardized previously IEEE 802.22 [23], another technology intended for deployment in TV band. Having more than one standard produced by IEEE caused in previous period market to be more reserved in deploying TVWS solutions. It had certain drawbacks in total amount of equipment produced and consequently the price. We expect that standardization will go further and that LTE TDD TVWS solutions will be better standardized and widely adopted for TVWS solutions due to precise specifications that are part or based on existing cellular technology standards.

Simplicity of installation of both technologies is relatively the same. End user devices are self-installed. It means that they could be pre-configured. We find that will future standards development, end users will not see the difference from the perspective of installation complexity.

TVWS devices could be considered as a small market comparing to cellular technologies. It is still in regulations phase and such regulatory ambiguities and lack of global standardization and compatibility limit the potential of the TVWS market. As in any other market, key for success is the deployment price per user. Due to large scale of production and more popular standard, LTE is seen as a better candidate regarding the price of end user devices and base stations. IEEE has produced in previous year more than one standard intended for TV band thus segmenting the market with different, low volume sets of equipment. As a consequence, IEEE 802.11af and IEEE 802.22 equipment is more costly to use comparing to LTE equipment, especially when end user devices are compared. One of the possibilities to lower deployment costs for IEEE 802.11af is to combine them with IEEE 802.11g/n/ac devices. In this scenario, IEEE 802.11af devices are used in point to multipoint network where TVWS connection serves as backhaul to regular Wi-Fi connection that distributes Wi-Fi signal further to end users. In this case, end users are not required to have IEEE 802.11af based device and they can use their smart devices (phones, tablets, laptops etc.) to connect to the network. What would be most cost efficient will depend from scenario to scenario but we can assume that TDD LTE will be more cost effective in urban and suburban areas while IEEE 802.11af will be more efficient in rural areas where it will be used to provide “islands” of Wi-Fi connectivity in remote communities.

3. SIMULATION SCENARIO

In order to compare most common deployment scenarios for IEEE 802.1af and TDD LTE systems, simulation has been performed in Wembley area, on the North-West from central London area. Area limited by Edgware, Stanmore, Wealdstone, Kingsbury and Colindale with total surface area of 50m² has been analyzed for coverage. This area could be treated as urban area, with buildings of several stories height and residential houses that usually have one or two stories.

Simulation has been performed using digital terrain model (DTM) with horizontal resolution of 5m×5m and vertical resolution of 2m. Clutter has been used with losses and heights for each of 10 classes used. Clutter covers from rural layer to dense urban (urban with 50m tall buildings).

Simulation has been performed using 10 base stations of each technology in order to provide coverage to the abovementioned area. As per [16, 18], heights of TVWS base stations (for both technologies) have been set to 20m. Transmission power has been set to different ranges, starting from 25dBm EIRP to 35dBm EIRP. User terminals were set to height of 1.5m for indoor reception (most common for TDD LTE) and to 10m (most common for IEEE 802.11af) as outdoor unit with outdoor antenna located at the top of the roof with 20dBm EIRP.

For TDD LTE, maximum number of users per base station (small cell) has been set to 32, which is current limit in commercially available equipment. For IEEE 802.11af CTS/RTS mechanism has been activated. In order to have same conditions, both technologies were set to 5MHz wide radio-channel.

Additional comments and analysis have been performed for IEEE 802.11af for 8MHz wide radio-channel. Other radio channel bandwidths haven't been analyzed due to assumed limited spectrum in urban areas. It was assumed that 20MHz (3 TV channels) of continues spectrum is not available in urban area thus simulation with TDD LTE and the maximum radio-channel bandwidth haven't been conducted. As per [20], up to 5 TV channels are available for TVWS deployment in almost 90% or area with small transmission powers, but they do not need to be consecutive and bundling them and performing frequency planning on such bundled channels might be a challenge. Propagation model has been set to ITU recommendation P.1546-5 [24].

In order to make comparison between deployment in urban and suburban and rural area, additional coverage analysis has been performed for the area surrounded by Crowborough, Haywards Heath, Lewes, Eastbourne and Hastings where TVWS coverage has been provided from the TV tower located in the Heathfield area. Transmission power has been set to maximum 36dBm EIRP with end user terminal configured as outdoor unit with directive antenna with 6dBi gain and 35 EIRP. Base station antenna has been set to 40m and end user antenna has been set to 10m above ground level. Unused part of TV spectrum has been used for TVWS signal transmission. One TV channel 8MHz wide, close to 550MHz, has been used to provide coverage to the area. This area is characterized by rather low mobile data throughput that is mostly limited to 1Mb/s to the end user.

In Fig. 1, coverage achieved in the London urban area using IEEE 802.11af based TVWS devices has been presented. End users are assumed to use directional antennas positioned at 10m height above ground level.

Fig. 1. Downlink coverage in the urban London region using IEEE 802.11af based devices.

In limit computation time, analysis range has been limited to 10km from each location. It can be seen that the area of interest has been covered with signal level above the sensitivity level of devices. All TVWS base stations have coverage range which is from 4.5km (BTS marked as TVWS 1) to over 5km (TVWS 3). It can be seen that there is certain coverage achieved beyond 5km range but such coverage is achieved on the rooftops of higher buildings, not for lower or even indoor positioned antennas and terminals. IEEE 802.11af BTSs transmit with 35dBm EIRP while end users are transmitting with 20dBm EIRP.

Coverage achieved by LTE TDD based TVWS BTSs has been presented in Fig. 2.

Fig. 2. Downlink coverage in TVWS network based on LTE TDD devices.

End users are assumed to use indoor devices at the height of 1.5m with 20dBm EIRP. Standard clutter propagation losses due to a wall or window penetration are 10dB and 6dB respectively. LTE TDD BTSs transmit with 25dBm EIRP. It is obvious that, with indoor positioned end user terminals, coverage is smaller and requires larger number of BTSs to achieve same level of coverage. Nevertheless, the range of an LTE TDD cell was from 3.5km to 5km which is similar to the range of a cell when IEEE 802.11af BTS is used. It shows that with lower power LTE TDD could achieve similar cell coverage. It can be easily explained by the fact that LTE TDD uses more advanced coding that IEEE 802.11af in the physical layer.

Reference Signal Received Power (RSRP) for the LTE TDD network was in the range from -105dBm to -57dBm with standard deviation of 9.5dB and median value of -80dBm.

On the other side, IEEE 802.11af has been designed for uncoordinated deployment. As such, it has all necessary mechanisms related to interference control that LTE TDD doesn't possess. It deploys CSMA which is natively designed to cope with interference in unlicensed spectrum. There has been a significant research conducted in order to optimize performance and maximize throughput in IEEE 802.11 networks [25, 26].

Radio link availability analysis has been performed for both technologies. Reliability for TVWS network based on IEEE 802.11af devices is in the range from 98.34% up to 100% in different distances from the BTSs, in the area of interest. For LTE TDD, in the area of interest in the London, it is only up to 98% with certain parts of the area with very low probability. It can be easily explained as LTE TDD, due to low power in the simulation doesn't achieve to cover complete area of interest in London.

Throughput per area has been simulated as well. In the case of IEEE 802.11af based network, there are overlaps in coverage of neighboring cells thus nomadic mobility and BTS roaming could be enabled in the network. On the other side, in the case of LTE TDD, due to lower power and indoor end users' terminals, there is no coverage overlaps between the cells. In the case of LTE TDD, minimum throughput achieved is approximately 4.3Mb/s per area and on the average around 5.5Mb/s. Available throughput per area for IEEE 802.11af is much bigger due to cell overlap, higher transmission power which allows higher order modulations to be used, comparing to LTE TDD, especially in shorter distances from the sites. Available throughput per area for IEEE 802.11af based network has been presented in Fig. 3.

As it was assumed during the simulation that at least 5 TV channels are available (based on scenarios described in [20]), it was assumed during the simulation process that number of available TV channels is not a limiting factor.

In the case of a rural environment, Fig.4, achieved cell range is close to 9km, for IEEE 802.11af BTS with 35dBm EIRP and user terminal operating at the same power level. End user antenna is at 10m above ground level (AGL) which is above rooftops in the case of the rural environment. BTS antenna is installed in the TV tower at 40m AGL.

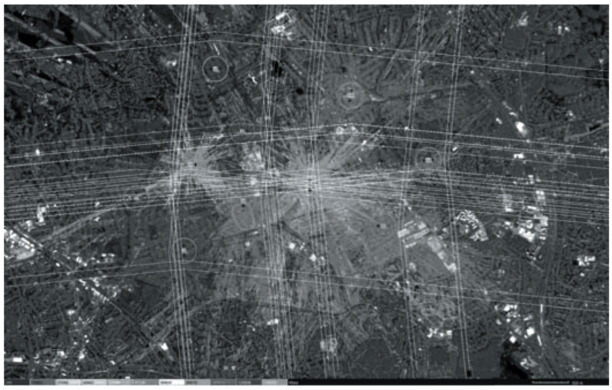

Fig. 3. Throughput per area from IEEE 802.11af based network.

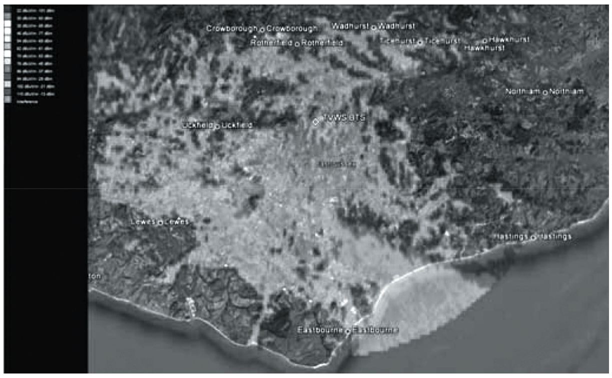

Fig. 4. Example of TVWS cell coverage in rural UK.

Only one TV channel is used and available channels have been determined analyzing used channels for TV broadcasting in the region, from the used TV tower and neighboring towers.

Although the range is much longer that in urban environment, such range is not applicable for point-to-multipoint (PtMP) connectivity, due to inefficient protocol adopted in IEEE 802.11af. CSMA and time windows adopted to avoid transmission collision are inefficient in such distances and it could be concluded that in such ranges point-to-point connections are achievable or IEEE 802.22 should be used as having protocols that would allow PtMP connectivity in longer distances.

4. FINANCIAL IMPLICATIONS

TVWS has been seen as a cheap alternative to existing wireless broadband services. It is no longer interesting exploring underserved population in countries with very poor telecommunication infrastructure but it is also interesting to compare adoption of TVWS networks and services in developed countries with good telecommunication infrastructure. It is obvious interest to explore possibilities to provide wireless broadband connectivity to underserved population and to different types of businesses. It is also interesting to explore possibilities to provide additional solutions for Internet of Things (IoT) connectivity and other machine-to-machine (m2m) connections.

In order to be seen as a candidate, TVWS solutions have to be cheap enough to be deployed in different scenarios that sometimes require mass adoption. Obviously, LTE TDD is seen as a better candidate due to technology that is standardized and adopted as a part of 4th generation standard of mobile communications. This would assure high production volumes if there is a demand and easier device interoperability. Although IEEE 802.11af could be described as scaled IEEE 802.11ac, it hasn't attracted enough of attention to achieve significant production levels.

As there is very limited number of small form factor user devices for IEEE 802.11af, LTE TDD is seen as a better candidate for the deployment where large number of end users is expected. Alternative is to use IEEE 802.11af where end user terminal is in the role of Wi-Fi access point (AP) or serves as a backhaul device to the Wi-Fi AP. Even smaller coverage range that was presented, due to selected scenarios, doesn't marks LTE TDD as more expensive solution. On contrary, due to cheaper end user devices and BTSs, even as twice as smaller coverage comparing to IEEE 802.11af, still makes LTE TDD more cost efficient solution.

5. CONCLUSION

Both IEEE 802.11af and LTE TDD could be used in order to deploy broadband wireless network at TV band, if radio spectrum is available. Due to very low RSL for TV units, TVWS devices, no matter of technology, are not seen as good candidates for operation on the secondary spectrum user basis. As per simulation in the urban London area, signal levels with-80dBm on average and down to -105dBm are still considerably high and above the minimum sensitivity levels of TV units. The achieved range of several kilometers in urban area for the cell range is more than adequate. If 4Mb/s is assumed as a minimum for video content streaming, Internet browsing and social networks activity, it can be concluded that end users could use basic broadband services in the selected environment. It could be concluded, due to limited spectrum, that cell ranges from 1km to 1.5km would be optimal for deployment in urban environment.

IEEE 802.11af has been well prepared for interference mitigation and operation in license free while LTE TDD will require certain improvements for operation in TVWS. Nevertheless, LTE TDD could be seen as a better candidate regarding capital and operations expenditures, equipment prices and easiness of installation in the case of mass deployment. It was demonstrated that IEEE 802.11af can serve as backhaul solution and the solution in rural environments with small number of users that require high transmission power, long range and moderate data rates for basic connectivity.

Based on the concluding remarks, it can be concluded that LTE TDD, with certain modifications, could be considered as a better candidate for deployment in TVWS.

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