Minimum Separation Distance Calculations for Incumbent Protection in LSA

Markku Jokinen[1(✉)], Marko Mäkeläinen[1], Tuomo Hänninen[1], Marja Matinmikko[2], and Miia Mustonen[2]

[1] Centre for Wireless Communications, University of Oulu, Oulu, Finland
{markku.jokinen,marko.makelainen,tuomo.hanninen}@ee.oulu.fi
[2] VTT Technical Research Centre of Finland, Oulu, Finland
{marja.matinmikko,miia.mustonen}@vtt.fi

Abstract. In this paper, we consider minimum separation distance calculations from the perspective of a real-life Licensed Shared Access (LSA) system in the 2.3 GHz band in Europe. In the LSA system, an LTE network shares spectrum resources with incumbent users, such as programme making and special events (PMSE) users, which need to be protected from harmful interference. Plenty of potential resources are available, in case the incumbent activity is occasional or localized. The sharing scenario requires realistic separation distances to be calculated to protect the incumbents. The minimum separation distances were calculated using methods presented in the ECC report on compatibility studies on 2.3 GHz band, but by using the parameters from the real-life LSA test network. With this work, we bridge the gap between theoretical research for incumbent protection and practical LSA deployment. In the process of defining new separation distances, discrepancies were found in the original example calculations.

Keywords: Minimum separation distance · Exclusion zone · Protection zone · Licensed Shared Access (LSA)

1 Introduction

As mobile traffic keeps increasing, new ways of finding more resources need to be established. One fundamental resource in mobile communication is spectrum, but since many different systems are allocated to dedicated frequency bands this resource is becoming scarce. On the other hand this allocated spectrum can be under utilized, hence spectrum sharing can be one solution to the lack of resources.

One of the emerging concepts of spectrum sharing is Licensed Shared Access (LSA) [1] that introduces additional licensed users on a shared basis. When applied to the mobile broadband, a mobile network operator (MNO) can share spectrum with different kinds of incumbent users in a licensed manner with quality of service (QoS) guarantees for all involved. In Europe, regulation framework [1] is ready for the 2.3–2.4 GHz for national deployment and standardization

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is ongoing to be used by both licensed and incumbent users. Incumbents in this band vary depending on national deployments and include e.g. aeronautical telemetry and programme making and special events (PMSE) applications. Research efforts are on-going to protect the incumbents, see e.g. [2]. Trialing this kind of new system is important for verifying usability and operation in practice. In Finland the LSA concept has been extensively trialed [3–5] in Core+ and Core++ projects [6] using Finnish LSA trial environment.

In the LSA concept protecting incumbent is the most important issue while ensuring good operational conditions for MNOs. There are several methods for incumbent protection. First method is to preserve a certain partition of the frequency band to the incumbent use and allow the operation of MNOs in other parts of the frequency band. Another method is to allow the shared use of the whole band by both systems. This method requires geographical separation between the systems [7]. In this paper, we concentrate on sharing scenario between PMSE and MNO users. The separation can be defined by calculating a minimum separation distance [8] between the PMSE user and the closest MNO network element or by defining a protection zone as an aggregate effect of the MNO network elements. To expand the generic work of [8], we apply the minimum separation distance calculations to the incumbent protection in LSA. We decided to use minimum separation distance calculations, because the amount of required network information and the calculational complexity is lower than with the protection zone method. Minimum separation distance calculations are a foundation of the protection zone method, thus giving us a good starting point for more advanced implementations.

2 LSA Concept and Trial Environment

The LSA concept allows the introduction of additional licensed users on bands currently used by incumbents on a shared basis. Only two additional blocks, LSA Controller and LSA Repository [9], are needed on top of the commercial LTE network for the LSA concept. Figure 1 illustrates LSA management system as a part of LSA architecture. Each MNO willing to operate on the LSA frequencies should have its own LSA Controller for managing its networks according to incumbent activity. The LSA Repository contains information about the operation of the incumbent as well as of the LSA Controllers and LSA Licenses for specific areas. The incumbent reports its location, frequency, operation time and type of incumbent to the LSA Repository. The LSA Controller receives this information from the LSA Repository and controls the MNO network accordingly. For making the decision of the spectrum usage, the LSA Controller uses information of the MNO network layout. The first implementation of the LSA concept is the Finnish LSA trial environment [3,4] that consists of commercial LTE base stations (BS), both macro and small cells, operating on 2.3 GHz TDD band. BSs are connected to the conventional LTE core network and Operations, Administration and Management (OAM) system. The core network provides internet connectivity to user equipments (UEs), the OAM side consists of NetAct OSS providing a single system for managing LTE network.

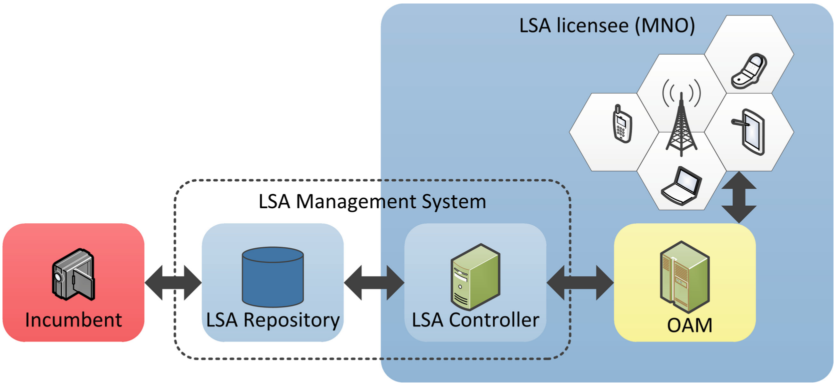

Fig. 1. LSA system arcitecture.

To protect the incumbent user from harmful interference, the LSA Controller needs to adjust the LTE network to achieve a given interference power, which depends on factors such as path loss and transmit power. This can be accomplished by setting the minimum separation distance between the MNO and the PMSE users to guarantee interference free operation at the same time and on the same frequency resource. Minimum separation distance can be expanded to an exclusion zone, if a circle with a radius of the separation distance is drawn around the incumbent receiver. These minimum separation distances calculations have been introduced in ECC report 172 [8]. However, the calculations were revised to reflect more realistic heterogeneous network environment used also in the Finnish LSA trial environment. The revised calculations lead to more realistic exclusion zones and makes the sharing scenario more efficient, not wasting spatial resources, but still guaranteeing interference free operation.

3 Minimum Separation Distance Calculation

For two systems to operate in same geographical area and same frequency band, an interference threshold needs to be set. An interfering transmitter generates a signal and the victim receiver needs to have sufficient protection against it to continue its operations. This protection can be achieved if there is a sufficient separation in the spatial domain between the interfering transmitter and the victim receiver. This means that the path loss between two systems is high enough. The other possibility is to have separation in frequency; transmit and receive filters can suppress the signal to a low enough level. More generally, a combination of both mechanisms is present in the system.

The ECC report 172 [8] introduces sharing scenarios for mobile broadband and incumbents in the 2.3 GHz band. In many European countries, an incumbent is a PMSE user for which the report introduces three different use cases: 1. Cordless camera link, which consists of a hand-held camera transmitter and a small portable receiver, 2. Mobile video link, where a transmitter is on top of a motorcycle and a receiver is carried by a helicopter, 3. Portable video link, which consists of a two-man camera team transmitter and a truck receiver. Scenarios 1. and 3. are located in an urban environment, scenario 2. takes place in a rural environment. The selection of the scenario has an effect on the used propagation model, therefore having significant effect on achieved separation distance. In our study, the coexistence scenarios studied involve LTE TDD (BS or UE) transmitters and video link receiver on the other end. Since the PMSE service has primary status on using the spectrum, the LTE system should not create interference against it. The systems are assumed to be deployed either in the same channel (co-channel case), in channels directly adjacent to each other (adjacent channel case), or with a guard band (alternate channel case). Figure 2 illustrates different channel cases [10], where B is the channel bandwidth and f_c is the center frequency.

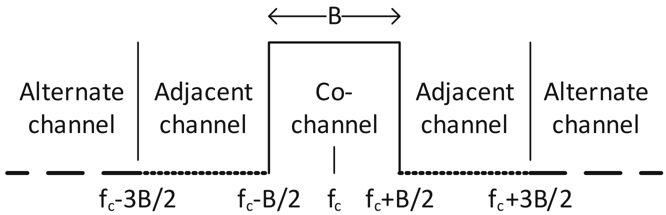

Fig. 2. Measurement mask normalized to channel bandwidth.

For calculating the minimum separation distance [8], first the median minimum coupling loss (MCL) is calculated, which defines the minimum required pathloss between an interferer and a victim receiver. It is calculated with,

$$MCL_{50} = P_t + G_t - G_{td} - G_{fe} + G_r - G_{rd} - IC - G_b, \tag{1}$$

where P_t [dBm] is transmitted power, G_t [dBi] is transmit antenna gain, G_{td} [dB] is transmit antenna directivity loss, G_{fe} [dB] is transmit antenna feeder loss, G_r [dBi] is receive antenna gain, G_{rd} [dB] is receive antenna directivity loss, IC [dBm] is interference criterion and G_b [dB] is bandwidth mitigation factor. Antenna directivity loss is caused if transmitter and receiver antennas are not pointed directly at each other. This can be considered in both vertical and horizontal directions. Feeder loss is mainly caused by cable attenuation in the base station tower. IC is the maximum allowable received interference level, where the interference limit is assumed to be 6 dB under thermal noise of the receiver. Value of 6 dB is commonly used in coexistence studies involving video links and MNO terminals. Thermal noise N [dBm] can be calculated with,

$$N = -174 + 10\log(B_r) + F, \tag{2}$$

where F [dB] is receiver noise figure and B_r is receiver bandwidth in Hz, all the later formulas consider bandwidths in MHz.

If two systems are not operating in the same channel e,g, they are in adjacent or alternate channels, not all transmitted power is effecting the victim. In the co-channel case all transmitted energy is received, hence $P_t = P_{MAX}$ [dBm], where P_{MAX} is maximum output power. In the adjacent channel case

$$P_t = \max(P_{MAX} - ACLRr; 10\log(B_t \cdot 10^{ACLRa/10})), \tag{3}$$

where the adjacent channel leakage ratio $ACLRr$ [dB] is a relative limit, compared to P_{MAX}, $ACLRa$ [dBm/MHz] is an absolute limit for LTE transmitter on adjacent channel. The less stringent limit [11] is used since we consider the worst-case scenario of interference. In the alternate channel case

$$P_t = 10\log(B_t \cdot 10^{I_{sp}/10}), \tag{4}$$

where I_{sp} [dBm/MHz] is a maximum absolute interference emission density in guard band and B_t is transmission bandwidth. Numerical values of $ACLR$ and I_{sp} can be found in Tables 6, 7, 20 and 21 in [8]. If the transmitter bandwidth is higher than the receiver bandwidth, only part of the transmitted energy is received. That is modeled with G_b a bandwidth mitigation factor. For the co-channel case

$$G_b = \max(0; 10\log(B_t/B_r)). \tag{5}$$

For the adjacent channel case the specific mitigation factor is subtracted from the previous equation. These values are derived from the transmitter emission masks and are presented in Table 23 in [8]. For the alternate channel case $G_b = 0$.

In the presence of fading, MCL_{50} limits the received interference under desired threshold only 50 % of the time. Fading statistics is taken into account to limit interference power under the threshold 95 % of time. Correction term for MCL_{50} is

$$MCL_{95} = MCL_{50} + \sigma \cdot \sqrt{2} \cdot \mathrm{erf}^{-1}(2 \cdot 0.95 - 1), \tag{6}$$

where erf^{-1} is the inverse error function, which results in the constant multiplier for σ that is the distance dependent standard deviation given in [12].

According to the MCL_{95}, the minimum separation distance can be calculated by using different propagation models depending on the calculation scenario. Different versions of Modified Hata propagation model and the Free space propagation model [12] was used in the calculations.

Effect of the directional antennas was modeled using ITU-R F.1336-2 [13] approach, because depending on antenna heights, distance and tilt angle, different antenna directivity loss is achieved. Effect of geometry between interferer and victim systems is illustrated in Fig. 3. The PMSE receiver antenna is assumed to be parallel with the surface of the earth. In this case, the angle α is used to define the receiver antenna directivity loss G_{rd}, meaning that the main beam of the receiver antenna is not pointing towards the transmitter. In the LTE BS antennas are usually tilted downwards, meaning that the tilt angle defines the

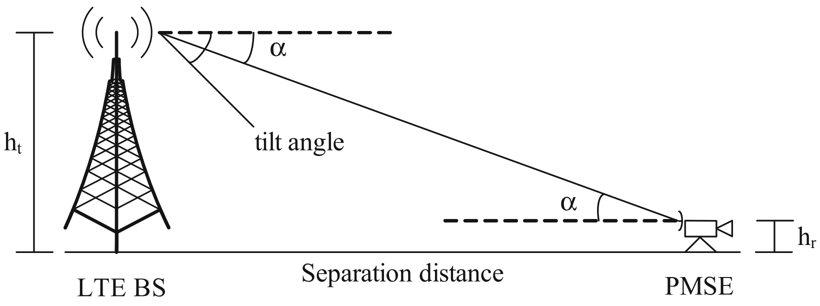

Fig. 3. Geometry between interfering transmitter and victim receiver.

main beam direction of the antenna. In this case, the effective angle for calculating G_{td} is $\alpha-$tilt angle. It should be noted, that the PMSE receiver in scenario 2 is located in the helicopter and is above the LTE BS antennas. In the horizontal domain, we always assume the worst case scenario where the maximum antenna gain is considered on both the interferer and the victim side.

Since there are distance dependent values that effect the MCL, like antenna directivity loss and fading standard deviation, calculation of the MCL is performed iteratively. In the iteration process we first give an initial guess for the distance value, and calculate the MCL accordingly. Then the MCL can be used to calculate the minimum separation distance and that distance can be used for fine tuning distance dependent values and recalculating the MLC. This iteration process is continued until saturation is achieved, meaning that two consecutive iterations give the same result with a three decimal accuracy. If the iterations are not saturating, meaning that the calculations are oscillating between two values, then average of consecutive iterations is used for the next iteration.

4 Verification of the Calculations

The minimum separation distances, obtained according to the previously presented methods, were calculated with different input parameters using Matlab model that was first verified by repeating calculations from [8].

Table 1 presents calculated values for the Cordless camera link use case. Documented values from ECC report 172 Table 25 [8] are reproduced in Table 2. Parameters used in the calculations are presented in Table 3. It should be noted that these parameters (as well as the separation distances in Tables 1 and 2) represent the typical small cell BS values, not those of a macro BS. In the calculations, Urban sub-case of Modified Hata propagation model was used. By comparing our results to the results given in the report, we can see that they match with high accuracy. Therefore it can be concluded that the created calculations are inline with those presented in [8]. This was true for all three use cases.

In a couple of scenarios there are differences in the results. They are marked with * in Table 2. An analysis of the results revealed that the discrepancies occur

Table 1. Cordless camera link use case, calculated results

			Interfering system and bandwidth B_t					
interference scenario	victim bandwidth B_r		LTE TDD BS			LTE TDD UE		
			20Mhz	10MHz	5Mhz	20Mhz	10MHz	5Mhz
co-channel	20 MHz	MCL (dB)	162.35	162.35	162.35	156.79	156.79	156.79
		d (km)	3.236	3.236	3.236	0.609	0.609	0.609
	10 MHz	MCL (dB)	162.35	165.32	165.32	156.79	159.80	159.80
		d (km)	3.236	3.930	3.930	0.609	0.741	0.741
	5 MHz	MCL (dB)	162.35	165.32	168.30	156.79	159.80	162.81
		d (km)	3.236	3.930	4.775	0.609	0.741	0.902
adjacent	20 MHz	MCL (dB)	129.37	127.77	127.77	139.91	139.91	139.91
		d (km)	0.375	0.337	0.337	0.202	0.202	0.202
	10 MHz	MCL (dB)	130.67	130.06	130.06	141.19	141.97	141.97
		d (km)	0.408	0.392	0.392	0.220	0.231	0.231
	5 MHz	MCL (dB)	131.51	130.98	131.85	142.16	142.63	143.91
		d (km)	0.431	0.416	0.441	0.234	0.241	0.262
alternate	20 MHz	MCL (dB)	130.68	128.62	125.54	129.96	125.40	119.03
		d (km)	0.408	0.357	0.292	0.105	0.095	0.086

in the adjacent channel scenarios. There are discrepancies in both the LTE BS and the LTE UE scenarios, recreating these results with our model means different changes in both scenarios. In the LTE BS scenarios, to replicate documented results, values of B_t and B_r need to be switched in Eqs. 2, 3 and 5. Also, from Eq. 5 the max-operator is left out, which limits the values to the positive side. Additionally, the specific mitigation factor needs to be added to G_b instead of subtracted from it, as it should be. In the LTE UE scenario to produce values marked with *, the specific mitigation factor is used as G_b value instead of subtracting it from G_b. As a conclusion, it is clear that there are some discrepancies in the calculations of the original report. Fortunately the differences are within an order of 1.5 dB and 40 m, thus the effect is not significant. Hence, by back tracking discrepancies in the original report, we can conclude that our code can be used to calculate separation distances more suitable for our trial network.

5 Results for LSA Concept and Trial Environment

Next the minimum separation distance calculations are applied to the LSA concept in the 2.3 GHz band for sharing between LTE and incumbent PMSE by using parameters from the Finnish LSA trial environment. Suburban below rooftop propagation model was used for the Cordless camera link and for the Portable video link use cases. This channel model represents our trial environment more accurately than Urban channel model used in reference calculations. Free space propagation model was used for Mobile video link use case. Separation distances were calculated also for a small cell scenario, where BS and UE are located inside of a building and are influencing the incumbent user outside. In the indoor to outdoor case, propagation models need to be modified. It is specified in [12] that an external wall creates additional (L_{we}) 10 dB attenuation to the signal and increases deviation caused by fading by (σ_{add}) 5 dBs.

Table 2. Cordless camera link use case, results from [8]

			Interfering system and bandwidth B_t					
interference scenario	victim bandwidth B_r		LTE TDD BS			LTE TDD UE		
			20Mhz	10MHz	5Mhz	20Mhz	10MHz	5Mhz
co-channel	20 MHz	MCL (dB)	162.3	162.3	162.3	156.8	156.8	156.8
		d (km)	3.236	3.236	3.236	0.609	0.609	0.609
	10 MHz	MCL (dB)	162.3	165.3	165.3	156.8	159.8	159.8
		d (km)	3.236	3.953	3.953	0.609	0.744	0.744
	5 MHz	MCL (dB)	162.3	165.3	168.3	156.8	159.8	162.8
		d (km)	3.236	3.953	4.780	0.609	0.744	0.900
adjacent	20 MHz	MCL (dB)	129.4	129.4*	129.4*	139.9	139.9	139.9
		d (km)	0.373	0.373*	0.373*	0.203	0.203	0.203
	10 MHz	MCL (dB)	128.7*	130.1	130.1	140.7*	142.0	142.0
		d (km)	0.359*	0.392	0.392	0.213*	0.231	0.231
	5 MHz	MCL (dB)	129.8*	131.0	131.9	141.8*	143.2*	143.9
		d (km)	0.385*	0.417	0.442	0.229*	0.250*	0.263
alternate	20 MHz	MCL (dB)	130.6			130.0		
		d (km)	0.408			0.106		

Table 3. Cordless camera link calculation parameters

Parameter	symbol	unit	LTE TDD BS	LTE TDD UE
Maximum transmit power	P_{max}	dBm	24	23
Tx antenna height	h_t	m	15	1.5
Rx antenna height	h_r	m	1.5	1.5
Transmit bandwidth	B_t	MHz	20, 10, 5	
Receive bandwidth	B_r	MHz	20, 10, 5	
Spurious emission	I_{sp}	dBm/MHz	−30	−30
Relative ACLR	ACLRr	dB	45	30
Absolute ACLR	ACLRa	dBm/MHz	−32	−30
Tx antenna gain (max)	dBi	G_t	17	0
Rx antenna gain (max)	dBi	G_r	16	16
Feeder loss	G_{fe}	dB	3	0
Rx noise figure	F	dB	4	4
Tx antenna tilt	tilt	degree	3	0
3dB vertical beamwidth	θ_3	degree	3	-
Center frequency	f_c	MHz	2310	2310

The results of the separation distance calculations are presented in Table 4 through Table 6. The results are calculated with parameters relevant to the trial environment, presented in Table 7. In the result tables, both macro cell and small cell scenarios are presented for both the BS and the UE scenarios. All these scenarios have been considered with three different incumbent use cases.

Table 4. Cordless camera link use case results for trial environment

			Interfering system and bandwidth B_t			
			macro cell		small cell	
interfenrece scenario	victim bandwidth B_r		LTE BS	LTE UE	LTE BS	LTE UE
			20 Mhz	20 MHz	20 Mhz	20 MHz
co-channel	8 MHz	MCL (dB)	188.26	151.79	151.52	144.17
		d (km)	42.88	0.971	1.275	0.591
adjacent	8 MHz	MCL (dB)	144.09	133.68	118.69	125.9
		d (km)	3.712	0.297	0.090	0.095
alternate	8 MHz	MCL (dB)	133.24	129.91	125.63	114.54
		d (km)	1.796	0.232	0.235	0.079

Table 5. Mobile video link use case results for trial environment

			Interfering system and bandwidth B_t			
			macro cell		small cell	
interfenrece scenario	victim bandwidth B_r		LTE BS	LTE UE	LTE BS	LTE UE
			20 Mhz	20 MHz	20 Mhz	20 MHz
co-channel	8 MHz	MCL (dB)	180.19	143.79	143.52	135.92
		d (km)	10182.2	154.2	149.5	62.32
adjacent	8 MHz	MCL (dB)	135.23	115.67	101.42	107.68
		d (km)	57.50	6.053	1.173	2.413
alternate	8 MHz	MCL (dB)	123.51	109.69	106.15	101.3
		d (km)	14.93	3.042	2.024	1.158

Table 6. Portable video link use case results for trial environment

			Interfering system and bandwidth B_t			
			macro cell		small cell	
interfenrece scenario	victim bandwidth B_r		LTE BS	LTE UE	LTE BS	LTE UE
			20 Mhz	20 MHz	20 Mhz	20 MHz
co-channel	8 MHz	MCL (dB)	202.22	165.79	165.52	157.92
		d (km)	85.09	4.805	5.749	2.872
adjacent	8 MHz	MCL (dB)	157.54	137.68	127.81	131.95
		d (km)	18.50	0.765	0.488	0.526
alternate	8 MHz	MCL (dB)	146.49	133.00	129.78	128.91
		d (km)	8.829	0.563	0.556	0.431

Parameters used in the calculations are following the format from [8,12,13], but are specific for the trial environment.

Parameters presented in Table 7 have multiple values for Rx antenna height and gain. These present the values for different use cases, the first one is for the Cordless camera link, the second is for the Mobile video link and the third is for the Portable video link use case. Differences in the parameters are due to the use case definitions. In the Cordless camera link case the receiver antenna is directional disk or Yagi standing on the ground. In the Mobile video link case,

Table 7. Calculation parameters for macro cell and small scenarios

Parameter	symbol	unit	macro BS	macro UE	small BS	small UE
Maximum Tx power	P_{max}	dBm	43	21	24	21
Tx antenna height	h_t	m	40	1.5	2.5	1.5
Rx antenna height	h_r	m	1.5, 150, 5			
Transmit bandwidth	B_t	MHz	20	20	20	20
Receive bandwidth	B_r	MHz	8	8	8	8
Spurious emission	I_{sp}	dBm/MHz	-30	-30	-30	-30
Relative ACLR	ACLRr	dB	45	30	45	30
Absolute ACLR	ACLRa	dBm/MHz	-15	-	-32	-
Tx antenna gain (max)	G_t	dBi	17	0	5	0
Rx antenna gain (max)	G_r	dBi	13, 5, 27			
Feeder loss	G_{fe}	dB	0.4	0	0.4	0
Rx noise figure	F	dB	4	4	4	4
Tx antenna tilt	tilt	degree	3	0	0	0
3dB vertical beamwidth	θ_3	degree	7	-	-	-
Center frequency	f_c	MHz	2380	2380	2380	2380
Wall attenuation	L_{we}	dB	-	-	10	10
Additional deviation	σ_{add}	dB	-	-	5	5

an omnidirectional receiver antenna is mounted on a helicopter levitating 150 m above ground. In the Portable video link case, a parabolic disk receiver antenna is mounted on top of a truck. In addition to these changes, different propagation models were used in the calculations. This time, the Tx and the Rx bandwidths were fixed according to the values used in the trial environment. It can be noted, that the macro cell BS has the highest transmit power and antenna gain, leading to the highest separation distances seen in the following paragraphs.

Results of the Cordless camera link use case are presented in Table 4. The co-channel scenario naturally results in the highest separation distances. When a macro cell BS is the interfering transmitter, almost 43 Km of separation distance is required. Separation distance is reduced to around 1.3 Km with a small cell BS interferer. The UE scenarios result in under 1 Km separation distance. In small cell scenarios both the BS and the UE are located inside, hence the external wall effect is taken into account. In the adjacent channel scenarios, the separation distance is under 4 Km and in the alternate channel scenario under 2 Km.

In the Mobile video link use case, separation distances are significantly higher than in the Cordless camera link use case. The propagation model in Mobile video link use case is Free space, which has lower attenuation than Hata models. Results of the Mobile video link use case are presented in Table 5. The MCL values are in the same scale as in the Cordless camera link use case, meaning that most of the increase in the separation distance is caused by a different propagation model. The results show up to 10000 Km of separation distance in the co-channel scenario which is not realistic and is due to the assumptions taken in the model (e.g. lack of considering the curvature of the earth). In the co-channel scenario, the UE and the small cell scenarios lead to separation distances between 150 to 60 Km. In the adjacent channel scenario, up to 58 Km of separation distance is achieved and the highest separation distance in the alternate channel case is almost 15 Km in the macro BS scenario.

In the Portable video link use case, the use of a highly directive receiver antenna and the assumption that the receiver and transmitter are pointing to each other increase the MCL values compared to the previous use cases. This means that also the separation distances are higher compared to the Cordless camera link use case. Results for the Portable video link use case are presented in Table 6. In the case of macro cell BS, the co-channel scenario separation distance is 85 Km, in the adjacent channel scenario 19 Km and in the alternate channel scenario 9 Km. All the other scenarios have significantly shorter separation distances varying from 6 Km to 400m.

6 Conclusion and Future Work

In this paper we have studied the problem of incumbent protection in LSA and calculated the minimum separation distances from LTE to incumbent PMSE in the LSA trial environment with realistic parameters. Calculations were done according to the principles presented in the ECC report 172 [8], the ERC report 68 [12] and the Recommendation ITU-R F.1336-2 [13]. Using these principles, numerical values for different PMSE system co-existence use cases were produced. By applying more realistic separation distances to the system, spatial resources can be used without causing interference to the incumbent user.

The LSA Controller can use parameters achieved from the current network deployment and from the PMSE system to adaptively calculate separation distances. This will make the LSA Controller more flexible to cope with the changes in environment of different network deployments and multiple types of PMSE. This is a useful feature when expanding the LSA deployment to a larger scale.

One future direction is to consider the incumbent protection with other methods, like extending this work to consider multiple interference sources and to calculate the protection zone for accumulated interference. Taking into account a mobile network layout consisting of multiple spatially separated BSs and UEs which are transmitting simultaneously on the same frequency band, the aggregate field strength may need to be considered instead of the minimum separation distance. However, adding more complexity to the interference calculations will lead to increased amount of information needed as well as more time needed for interference calculations. This will make it more challenging for example to follow changing location of an incumbent with mobility.

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