CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

Spectral Requirements of Wireless Broadband Networks for the Airport Surface

Dr. Izabela Gheorghisor

The MITRE Corporation

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Outline

- Introduction
- Characteristics of IEEE 802.16e OFDMA
- Physical Layer Data Rates Considerations
- Potential Applications for the Airport Surface
- Spectral Requirements Estimation Approach
- Spectral Requirements Estimation Results
- Conclusions

Introduction

- Wireless broadband networks based on the IEEE 802.16 family of standards are analyzed in an airport environment
  - Airport Network and Location Equipment (ANLE)
  - IEEE 802.16e-2005
    - Expands IEEE 802.16-2004 for mobile users
    - The Orthogonal Frequency Division Multiple Access (OFDMA) implementation is scalable
- The OFDMA implementation of IEEE 802.16e is analyzed
  - Physical layer data rates are obtained
- Aggregate data rate requirements are estimated for a set of potential future applications at a large airport (DFW)
- A spectral requirements estimation methodology is developed and applied for the given set of potential future applications

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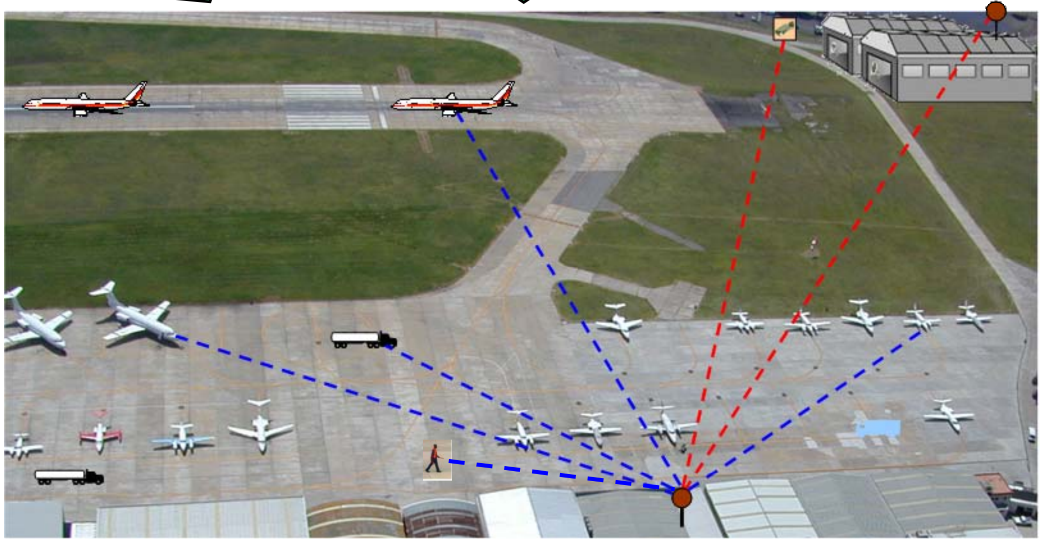
Wireless Broadband Network in an Airport

Increasing demand in airport surface data transmission

Need for broadband connectivity to mobile platforms

High installation cost of running new cable or fiber



Flexible and scalable network architecture to adapt to evolving airport configurations

Mobile
Fixed

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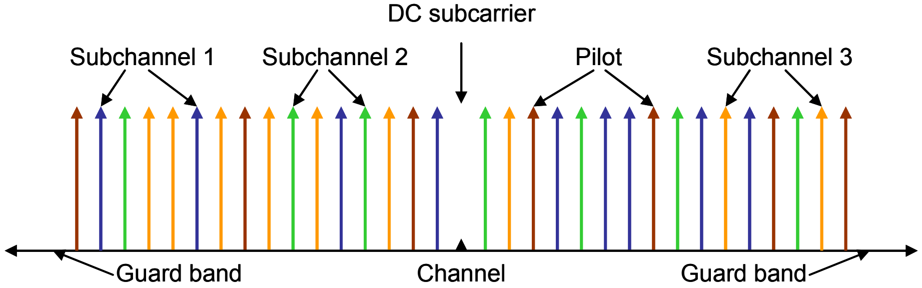
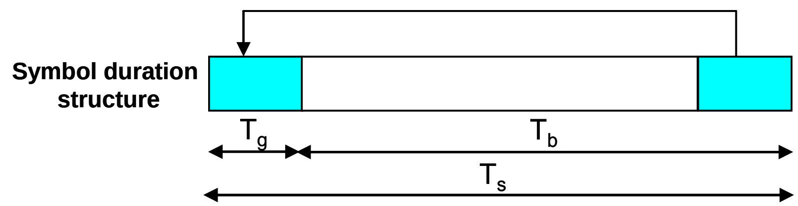
Characteristics of IEEE 802.16e OFDMA

OFDMA Frequency Structure



Symbol Time Structure



Scalable OFDMA Channelization Parameters

Parameters	Values			
System Channel Bandwidth (BW) (MHz)	1.25	5	10	20
Sampling frequency (F_s) (MHz)	1.4	5.6	11.2	22.4
FFT Size (N_{FFT})	128	256	1024	2048
Subcarrier spacing (Δf) (kHz)	10.94			
Useful Symbol Time (T_b) (μs)	91.4			
Guard Time (T_g=1/8*T_b) (μs)	11.4			
Symbol Duration (T_s) (μs)	102.9			

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Physical Layer Parameters

	OFDMA PUSC			
Parameters	**FL**	**RL**	**FL**	**RL**
Channel Bandwidth (BW) (MHz)	20		10	
FFT Size (N_{FFT})	2048		1024	
Sampling factor (n)	1.12		1.12	
Subcarrier spacing (Δf) (kHz)	10.94		10.94	
Cyclic prefix ratio ($G=T_g/T_b$)	1/8		1/8	
OFDM Symbol Duration (T_s) (μs)	102.9		102.9	
Frame duration T_{FR}(ms)	5		5	
Number of OFDM symbols/frame (N_{OFDM})	48		48	
Number of transmitted OFDM symbols/frame (N'_{OFDM})	47		47	
Number of data subcarriers (N_{data})	1440	1120	720	560

FL = forward link **RL = reverse link**

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Maximum Physical Layer Bit Rates

Modulation	Coding Rate	Rx. SNR (dB)	Max OFDMA PHY Bit Rate (Mbps)			
			BW = 20 MHz		BW = 10 MHz	
			Forward Link	Reverse Link	Forward Link	Reverse Link
QPSK	1/2	5	13.54	10.53	6.77	5.26
	3/4	8	20.30	15.79	10.15	7.90
16-QAM	1/2	10.5	27.07	21.06	13.54	10.53
	3/4	14	40.61	31.58	20.30	15.79
64-QAM	1/2	16	40.61	31.58 (1)	20.30	15.79 (1)
	2/3	18	54.14	42.11 (1)	27.07	21.06 (1)
	3/4	20	60.91	47.38 (1)	30.46	23.69 (1)

- **Maximum rates shown assume transmission is *either* on FL *or* RL**
  - **If FL:RL ratio is 1:1, then maximum rates on FL and RL would be *half* the values in the table.**

(1) Implementation is optional

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Maximum Physical Layer Data Rates

Modulation	Coding Rate	Rx. SNR (dB)	Max OFDMA PHY Data Rate (Mbps)			
			BW = 20 MHz		BW = 10 MHz	
			Forward Link	Reverse Link	Forward Link	Reverse Link
QPSK	1/2	5	12.67	9.41	6.34	4.70
	3/4	8	19.01	14.11	9.50	7.06
16-QAM	1/2	10.5	25.34	18.82	12.67	9.41
	3/4	14	38.02	28.22	19.01	14.11
64-QAM	1/2	16	38.02	28.22 (1)	19.01	14.11 (1)
	2/3	18	50.69	37.63 (1)	25.34	18.82 (1)
	3/4	20	57.02	42.34 (1)	28.51	21.17 (1)

- **Maximum rates shown assume transmission is *either* on FL *or* RL**
  - **If FL:RL ratio is 1:1, then maximum rates on FL and RL would be *half* the values in the table.**

(1) Implementation is optional

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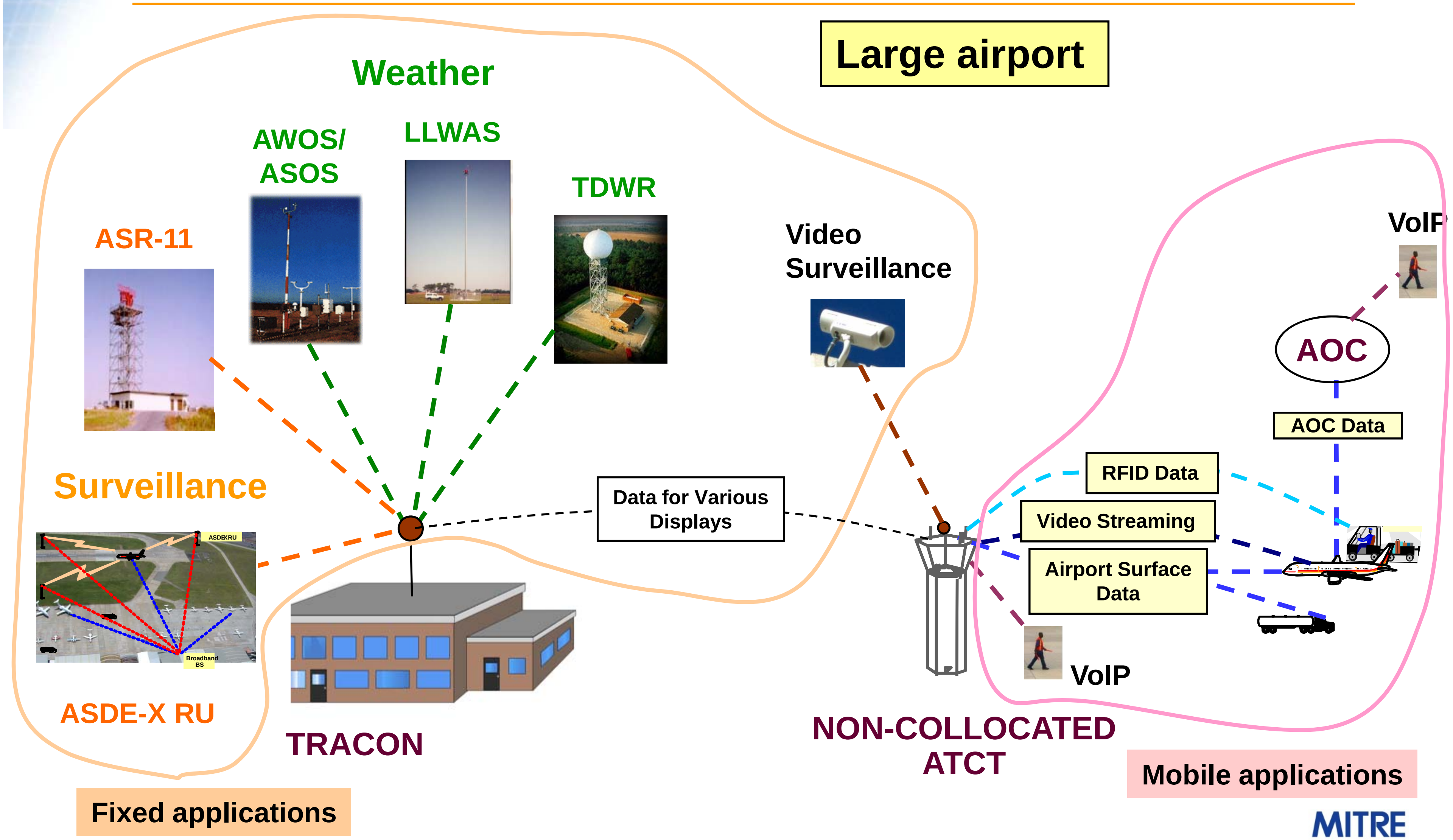
Potential Applications for the Airport Surface



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Aggregate Data Rate Requirements

Potential Application Classes

- Mobile
- Fixed

High density (HD) airport

Aircraft Counts (1)

Airport Position	Phase 1		Phase 2	
	HD	LD	HD	LD
Clearance/Ramp	134	4	194	7
Ground	48	3	70	4
Tower	18	5	26	8
Total	200	12	290	19

(1) From the Communications Operating Concept and Requirements (COCR) document

Application Class Type	Maximum Estimated Aggregate Data Rate per Airport (Mbps)					
	Phase 1			Phase 2		
	FL	RL	Total	FL	RL	Total
Mobile	5.2	3.0	8.2	15.2	4.4	19.6
Fixed	18.8	33.8	52.6	18.8	33.8	52.6
Total	24.0	36.8	**60.8**	34.0	38.1	**72.1**

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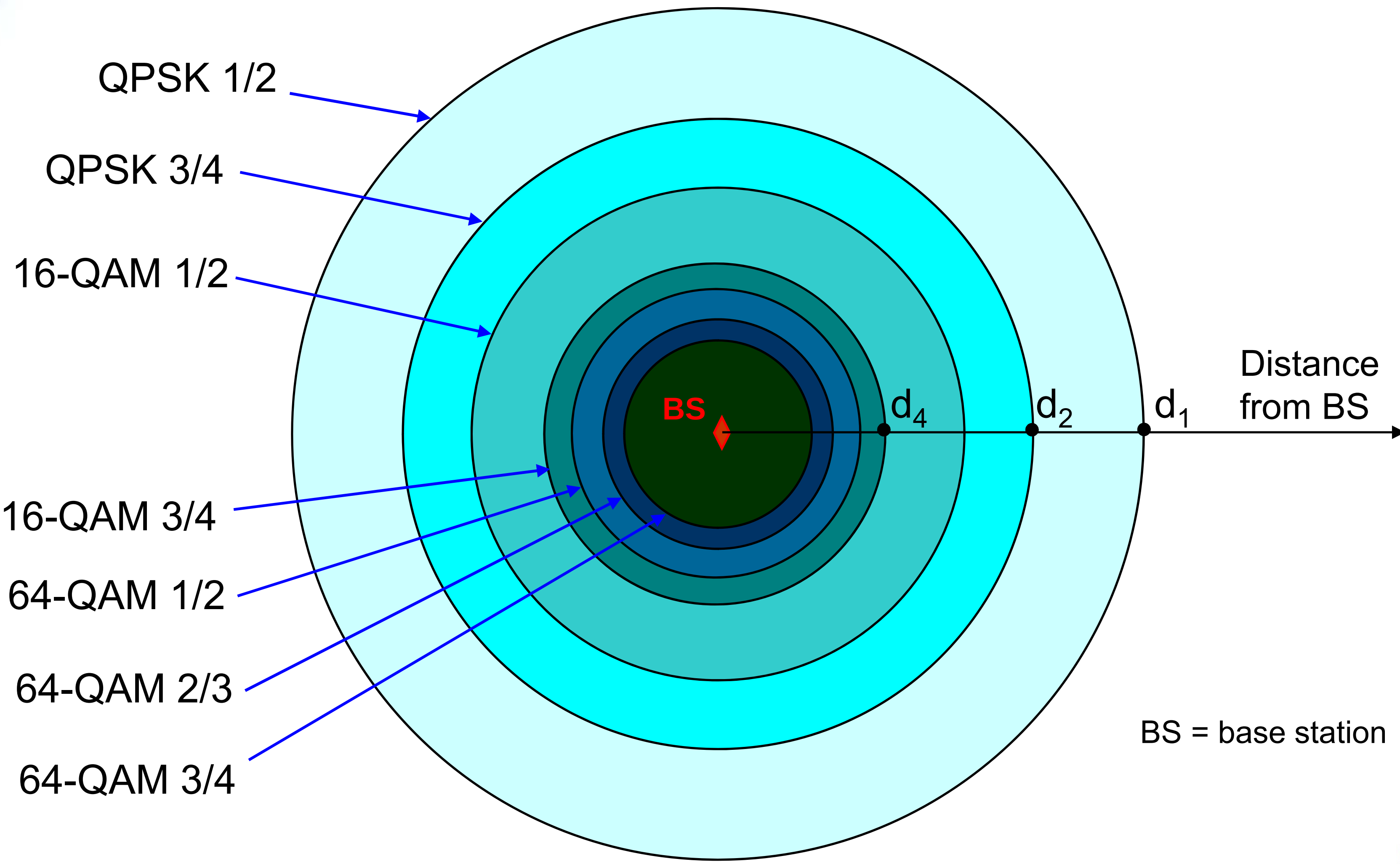
Adaptive Modulation



Adaptive Modulation (cont.)

Modulation	Coding Rate	Modulation Type (i)	Calculated Distance Ratio d_i/d_1	Calculated Probability P_i
QPSK	1/2	1	1	0.45
	3/4	2	0.74	0.22
16-QAM	1/2	3	0.58	0.17
	3/4	4	0.41	0.05
64-QAM	1/2	5	0.33	0.04
	2/3	6	0.27	0.02
	3/4	7	0.22	0.05

$$d_i = d_1 10^{\frac{-\Delta SNR(i)}{10n}}$$

$$\Delta SNR(i) = SNR_i - SNR_1$$

d_1 = distance from the base station to the edge of the coverage area
n = path loss exponent ; n = 2.3 (based on [1])

$$P_i = 10^{\frac{-2\Delta SNR(i)}{10n}} - 10^{\frac{-2\Delta SNR(i+1)}{10n}} \quad \text{for i =1…6}$$

$$P_i = 10^{\frac{-2\Delta SNR(i)}{10n}} \quad \text{for i = 7}$$

[1] Email communication with Dr. D. Matolak (April, 2008)

Spectral Requirements Estimation Approach

- **Average physical layer data rates**

For BW = 20 MHz: $R_{davg}^{(FL)} = 21.12\ Mbps$ $R_{davg}^{(RL)} = 16.13\ Mbps$

For BW = 10 MHz: $R_{davg}^{(FL)} = 10.67\ Mbps$ $R_{davg}^{(RL)} = 8.2\ Mbps$

- **Evaluate spectral efficiencies**
  - **FL and RL**
  - **Separate the broadcast (denoted as bc) application from the rest of the FL data**
    - **Assume broadcast data is transmitted at the lowest modulation (QPSK ½)**
- **Evaluate total bandwidth requirement**

$$S_{EFFd}^{(FL)} = \frac{R_{davg}^{(FL)}}{BW_S} \qquad S_{EFFd}^{(FL)(bc)} = \frac{R_d^{(FL)(bc)}}{BW_S} \qquad S_{EFFd}^{(RL)} = \frac{R_{davg}^{(RL)}}{BW_S}$$

$$BW_{avg}^{(req)} = ceil\left(\left(\frac{R_{dreq}^{(FL)(bc)}}{n_s S_{EFFd}^{(FL)(bc)}} + \frac{R_{dreq}^{(FL)} - R_{dreq}^{(FL)(bc)}}{S_{EFFd}^{(FL)}} + \frac{R_{dreq}^{(RL)}}{S_{EFFd}^{(RL)}}\right) / (\rho_{ch} BW_s)\right) BW_S$$

n_s=number of sectors/cell ρ_{ch} = channel loading factor

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Spectral Requirements Results and Conclusions

COCR Implementation Phase	BW = 20 MHz		BW = 10 MHz	
	Maximum Estimated Data Rate (Mbps) for a Large Airport	Estimated Spectral Requirements (MHz)	Maximum Estimated Data Rate (Mbps) for a Large Airport	Estimated Spectral Requirements (MHz)
Phase 1 (2020)	60.8	100	67.0	100
Phase 2 (beyond 2020)	72.1	120	78.3	110

- **Estimated spectral requirements of at least 100 MHz were obtained for an ANLE network at a large airport.**
- **These estimates exceed the amount of spectrum currently available in the 5091-5150 MHz band.**

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