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**Spectrum requirements for surface
applications at airports in the 5 GHz range**

M Series
**Mobile, radiodetermination, amateur
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REPORT ITU-R M.2232

Spectrum requirements for surface applications at airports in the 5 GHz range

(2011)

Summary

In this report, two methods determine the minimum required bandwidth to satisfy an identified demand for airport surface communications application. Based on the traffic requirement as detailed in Annex 1, the two methods applied in this report provide results depending on different criteria balanced between network capacity, deployed topology and the corresponding demand for frequency bandwidth.

1 Introduction

Aeronautical applications supporting surface applications at airports – including data links – are distinguished by a high data throughput but only moderate transmission distances, and it is expected that a single resource can be shared at multiple geographic locations. The system to support such applications will be implemented in some portion of the 5 000-5 150 MHz band.

Administrations and the International Civil Aviation Organization (ICAO) performed studies in order to determine the amount of spectrum needed for aeronautical airport surface applications in the 5 GHz frequency range [1]. The results, while preliminary, provide an order of magnitude of expected spectrum requirements and further the work begun in Report ITU-R M.2120 [2]. The results of expected spectrum requirements, irrespective of any reference to a given service, in the 5 GHz range are incorporated in this Report.

2 Potential applications for the airport surface communications

Airport surface wireless systems could provide the means of transporting data in the airport environment. With terminals located on the ground, on taxiing aircraft, and on parking aircraft, the systems are envisioned to support short-range, high-data-rate applications. Data rate requirements are calculated for two phases: Phase 1 (2020) and Phase 2 (beyond 2020) (see Annex 1). This Annex gives detailed information about the application and the expected data rate. For Phase 1 a data rate of 90 Mbit/s has to be carried by the system. For Phase 2 a data rate of 130 Mbit/s is estimated.

3 Assumptions

The following assumptions are commonly used in both methods described in § 4.

- Use of WiMAX 802.16e communications protocols.
- Propagation model in accordance with Annex 1, §§ 3.4 and 3.5 of Report ITU-R M.2118 [22].
- Averaged data rate in a cell is based on the following modulation schemes offered by WiMAX systems as shown in Table 1.

TABLE 1
Modulation data rates (WiMAX)

Modulation	Coding rate	Rx. SNR (dB)	Max OFDMA PHY data rate		Max OFDMA PHY data rate	
			BW = 10 MHz		BW = 20 MHz	
			Forward link	Reverse link	Forward link	Reverse link
QPSK	$\frac{1}{2}$	5	6.34	4.7	12.67	9.41
	$\frac{3}{4}$	8	9.5	7.06	19.01	14.11
16 QAM	$\frac{1}{2}$	10.5	12.67	9.41	25.34	18.82
	$\frac{3}{4}$	14	19.01	14.11	38.02	28.22
64-QAM	$\frac{1}{2}$	16	19.01	14.11	38.02	28.22
	$\frac{2}{3}$	18	25.34	18.82	50.69	37.63
	$\frac{3}{4}$	20	28.51	21.17	57.02	42.34

- Resulting in:
 - a forward link average data rate in a 20 MHz channel: 21.12 Mbit/s
 - a reverse link average data rate in a 20 MHz channel: 16.13 Mbit/s
- The same overall power transmitted over the airport
- List of applications as detailed in Annex 1
- Square-shaped model airport of $5 \times 5 \text{ km}^2$ size.

4 Spectrum requirement for airport surface communications

Two separate studies with different methods deriving the spectrum requirement for airport surface communications networks are described in the following two sections.

4.1 Method A

4.1.1 Estimation of spectrum requirement

Initially, estimates for surface spectrum requirements were determined using throughput estimates based on a review of current surface communication requirements, limited to those supporting safety and regularity of flight, at a major airport¹ in the United States of America. Those estimates were then augmented by new applications for the airport surface network that have arisen during its performance requirements/standardization activities. Those total throughput requirements were then assumed satisfied using the candidate surface system technology (based on the Institute of Electrical and Electronics Engineers (IEEE) Standard IEEE 802.16e), and an overall spectrum requirement was derived.

The International Civil Aviation Authority (ICAO) has identified a system based on the IEEE 802.16e Standard, which specifies the air interface for broadband wireless access (BWA) systems, including mobile subscribers moving at vehicular speeds. The standard is also flexible in

¹ For this study, Dallas-Fort Worth airport in the United States of America was examined.

that it can be implemented in bands below 10 GHz and with channel bandwidths from 1.25 MHz to 20 MHz. The approach followed for the spectrum requirements study involved:

- 1) cataloguing the potential message traffic for the airport network. For this study two implementation phases were assumed: up to 2020 (Phase 1) and beyond 2020 (Phase 2);
- 2) determining the airport data rate (bit/s) requirement to satisfy that message traffic (see Annex 1);
- 3) developing assumptions on the distribution of network participants². In order to minimize total spectrum required the assumption is made that the airport network infrastructure is installed to ensure use of higher modulation and coding schemes (i.e. 16-QAM 3/4 and above) everywhere in the gate/ramp areas and for all Category 2 applications³;
- 4) developing assumptions on the network channel structure (for this analysis, channel bandwidths of 10 and 20 MHz were considered) and channel loading;
- 5) estimating spectrum requirements based on the above assumptions.

Tables 2 and 3 contain the estimated spectrum requirements for an airport surface network at a major airport supporting the assumed applications. Table 2 addresses only airport surface communications between aeronautical stations and aircraft stations (Category 1⁴). Table 3 includes total requirements. As previously mentioned, two different channel bandwidths (10 MHz and 20 MHz) were considered. For the 20 MHz bandwidth case omnidirectional antennas were assumed for the base stations, while for the 10 MHz case sectorized (three sectors per base station) antennas were assumed. The calculation of the airport data rate requirement (Item 2 above) is detailed in Annex 1.

TABLE 2

Category 1: Airport surface communication requirements between aeronautical stations and aircraft stations ^(*)

Implementation phase	Channel BW = 20 MHz		Channel BW = 10 MHz	
	Maximum estimated data rate for a large airport (Mbit/s)	Estimated spectrum requirements (MHz)	Maximum estimated data rate for a large airport (Mbit/s)	Estimated spectrum requirements (MHz)
Phase 1 (2020)	38.9	60	44.4	60
Phase 2 (post 2020)	77.8	80	83.3	90

^(*) These values are estimated based on specific parameters and assumptions. Further study discussed below could serve to increase or decrease these estimates.

² Since the IEEE 802.16e Standard supports adaptive modulation and coding, channel throughput in bits per second will vary depending on the signal-to-noise ratio (SNR) for the particular communication path under consideration. Except as noted elsewhere, in order to provide a representative mix of SNRs the subscriber units were assumed uniformly distributed across the airport surface.

³ See Annex 1 for example applications under Categories 1 and 2.

⁴ See Annex 1 for example applications under Categories 1 and 2.

TABLE 3

Overall airport surface communication requirements^(*)

Implementation phase	Channel BW = 20 MHz		Channel BW = 10 MHz	
	Maximum estimated data rate for a large airport (Mbit/s)	Estimated spectrum requirements (MHz)	Maximum estimated data rate for a large airport (Mbit/s)	Estimated spectrum requirements (MHz)
Phase 1 (2020)	91.4	100	96.9	100
Phase 2 (post 2020)	130.3	120	135.8	130

^(*) These values are estimated based on specific parameters and assumptions. Further study discussed below could serve to increase or decrease these estimates.

4.1.2 Remarks concerning Method A

Certain observations can be made on the estimates in Tables 2 and 3, that could have a further impact on the results:

- Refining the assumption that all the subscriber stations are uniformly distributed over the airport surface, as well as taking advantage of advanced features of the 802.16e Standard such as “smart” antennas, may serve to reduce the required spectrum. Care must be taken however to ensure that the use of any such enhancements does not impact compatibility with other services using the bands. For example, the addition of multiple base stations on an airport, base stations with sectorized antennas, and/or the use of directional antennas for certain high data rate user applications could raise the available carrier-to-noise (C/N), facilitating the use of higher-rate modulations and reduced spectrum requirements. Such use might also reduce compatibility with other users of the spectrum which, in turn, may reduce the number of airports at which a given portion of spectrum is available. This could impact the overall spectrum requirements.
- The surface network spectrum requirements are scenario-dependent, however the methodology utilized for this study could be applied to other aviation scenarios as well. In particular, detailed analyses are needed to determine data traffic at airports and to determine the impact of sectorized antennas on fulfilling those traffic requirements.
- The impact of the channel loading factor should be analysed in detail. The value of 0.75 used for this study is fairly ambitious and needs verification, through modelling and simulation, by using traffic models for the aeronautical applications. It is unlikely that it would move in any direction other than down, and it should be noted that using a lower value could serve to increase the amount of spectrum required.
- While header compression was not assumed for this analysis, and in the end state header compression may reduce spectrum required, such reduction may be small and would not change the overall conclusion, if that is the case.
- The broadcast/multicast features of the IEEE 802.16e Standard should be further explored, however it is anticipated that they would require a more complicated frame structure which could increase the overhead, so it is not expected to reduce overall spectrum requirements.
- While a more detailed analysis could refine the traffic distribution between the forward and reverse links, it may not impact the total spectrum requirement.
- The analysis assumes that the airports equipped with the airport surface system are beyond radio line-of-sight of each other such that frequencies can be reused airport-to-airport with

no restrictions. If this assumption should prove incorrect, additional spectrum will be required.

- The airport surface system performance requirements/ standards development process began in 2010. The number of applications for the system may change during that process, resulting in different spectrum requirements.

4.2 Method B

4.2.1 Spectrum requirements

Based on the assumptions in § 3, considering the current frequency reuse capability offered by WiMAX 802.16e leads to show that the 20 MHz should be sufficient to address the data rate required by the list of applications detailed in the Annex.

One of the added value of WiMAX 802.16e is that it stands for a reuse one technology, that is to say that it has the capability of reusing the same frequency pattern on different cells [16].

This capability is more than a theoretical one since performance analyses have been published in several papers such as:

- Analyses based on simulations: See associated performances evaluation in Mobile WiMAX – Deployment Scenarios Performance Analysis [17].
- Simulations confirmed by real deployment data: WiMAX System Performance Studies [18].

Consequently, Table 4 shows the amount of spectrum that would be required to support the total specified requirements as described in Tables 6 and 7, respectively. The number of base stations assumes that the traffic is uniformly spread over the airport. In this case, the use of three sectorized antennas decreases the number of deployed antennas while significantly increasing the overall traffic capacity in far less spectrum.

TABLE 4

**Network topologies with a channel bandwidth of 20 MHz
overall airport surface communication requirements**

Implementation Phase		Maximum estimated data rate (Mbit/s)	OFDMA Channel BW = 20 MHz		OFDMA Channel BW = 10 MHz	
			Estimated spectral req. (MHz)	Minimum number of BS*	Estimated spectral req. (MHz)	Minimum number of BS*
Cellular network with frequency reuse factor of one	Phase 1 (2020)	91	20	6	10	10
	Phase 2 (> 2020)	130	20	7	10	14

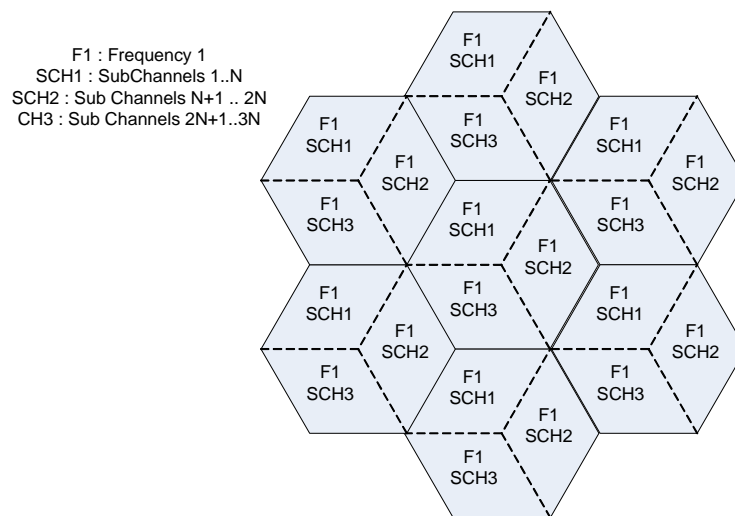
- Choice of 20 MHz channel: The most demanding application, as expressed in [1], is the 4D weather data, with an aggregated data rate of 4455 kbit/s. Taking into account the efficiency of the QPSK modulation (see Table 1), this demanding application requires WIMAX channels bandwidth higher than 5 MHz. 10 or 20 MHz channels can then be considered. To ensure additional flexibility in the sub carrier management, a 20 MHz channel is considered.

- Load factor: Taking into account the distribution between forward link and reverse link applications as expressed in [1] and based on Table 4 the overall load factor of the channels is then low.
- Overall power radiated over the airport: when the density of cells increases, the geographical area covered by each cell is reduced. Consequently the e.i.r.p. of each base station is reduced accordingly.

The Quality of Service management is achieved in an IEEE 802.16e network by using smart sub-carrier allocations between adjacent cells. This measure avoids interference between cells. The basic approach to insure an inter cell outage probability close to zero is to allocate fix sub channels from one sector to another (allowed since the load factor of the proposed topology is low).

FIGURE 1

Typical channel plan to decrease unfavourable co-channel interference between cells



The flexibility offered by the OFDMA is such that the network can be deployed with additional cells in order to decrease the overall load factor of the channels and therefore to minimize the inter channel interference, which results in an improved Quality of Service. Several channels can be dynamically assigned to increase capacity in particular areas as required.

4.2.2 Example of antenna installation in an airport environment

Figure 3 shows existing installations of radio antenna sites at Frankfurt/M airport in Germany which are used by different radiocommunication applications for various purposes. Each antenna site was selected to comply with the safety conditions as given by the airport environment. Shown are only the antennas in the vicinity of taxiways and runways for aircraft movement. The antenna site shown with a red circle refers to a set of equipments mounted up to 22 m on a mast and the blue circle refers to an installation of about 3 m height located between a taxiway and a one of the runways⁵. Due to the particular restrictions of airport installation in the vicinity of manoeuvring aircrafts, masts and other installation sites are usually shared by antennas of different mobile radio networks as well as antennas of other radio services.

For example, one cellular network at Frankfurt Airport capacity is shared among a variety of airport services, passengers and visitors under commercial service level contract conditions. The total

⁵ More detailed information for each installation is available under <http://emf2.bundesnetzagentur.de/karte.html?lat=50.040301151586064&lon=8.578734397888183&zoom=15>

occupied bandwidth is 10 MHz (2 by 5 MHz in the 2 100 MHz band). Other commercial providers have similar networks at Frankfurt/M with similar available bandwidth. Information about the actually achieved performance is proprietary and thus cannot be disclosed herein. However, as the network described in this example has operated now for several years, it can be assumed that it provides the appropriate quality of service for its intended applications.

Aviation networks operating in a dedicated band could provide even larger capacity or increased margins than the example shows as these networks could be operated under dedicated network management conditions and if necessary comply with special safety and security requirements. Different installations of single or multiple channel network topologies comprising 20 MHz, 10 MHz, and/or 5 MHz channels could be tailored to the demands of particular airport environments and the potential needs for network operations by different network operators.

FIGURE 2

Example of existing antenna sites in Frankfurt airport (F., Germany) (Map Source: Tele Atlas)



Further examples of a high-QoS/high-capacity network implementations in an airport environment can be found in (currently) 60 major airports in the US including Dallas, Fort Worth. The entire network in the airport area runs on a single 2×5 MHz 700 MHz FDD channel providing high-capacity mobile broadband coverage to all customers.

4.2.3 Remarks concerning Method B

With a network design based on frequency reuse factor 1 the total traffic payload is carried over the density of the cells. In addition to the low spectrum bandwidth demand that is needed by this cellular network approach, several other advantages are worth mentioning:

- In current cellular network designs, narrow sector antennas are used (usually more than 12 sectors per site are deployed in commercial cellular networks) leading to a further improvement in spectrum efficiency and overall system capacity.
- The antenna pattern can be tilted down to reduce radiation towards satellite services sharing the frequency band.

- Antenna improvements such as the use of MIMO techniques can be envisaged to optimize the average capacity of a channel and therefore reduce the required number of base stations to be deployed. The analyses of the improvements of MIMO antenna can be found in [19].

Further observations can be made when using a network design based on a frequency reuse factor of one while fulfilling the traffic and quality of service requirements as given in Tables 6 and 7, respectively:

- The major difference between the two network approaches is that Method B uses the highest possible degree of frequency reuse. This topology would need 20 MHz of total bandwidth to provide the same traffic throughput as per Tables 6 and 7⁶.
- The 5 091-5 150 MHz band contains 59 MHz of AM(R)S spectrum. As a result Method B offers the possibility of using more than one channel if necessary.
- Table 4 provides a topology applying a frequency reuse factor of 1 based on a limited set of assumptions. Required infrastructure may change when aeronautical requirements are considered.
- A uniform distribution of traffic over the airport is assumed. However, if the distribution is non-uniform a standard cellular approach provides more flexibility by using higher cell density in the high traffic regions, e.g. with adapted antenna patterns.
- For both approaches, improved antenna techniques, such as state-of-the-art MIMO, can be applied to improve the frequency efficiency (e.g. as used in deployed Korean networks) increasing the overall system capacity and thus reducing the overall spectrum requirement.
- A cellular deployment with a frequency reuse factor of one can also be optimized to ensure RF compatibility with all services operating in the band 5 091-5 150 MHz. For example, sectorized antennas, together with electrical and mechanical down tilt, can be used to limit radiation towards the sky.
- Such topologies are already in use in commercial networks in civil airport environments at several large airports such as Frankfurt/M, Germany, Midway International Airport, Chicago, USA, London Heathrow, UK, Schiphol Airport, Amsterdam, and several others around the world.
- The high bandwidth efficiency may lead to new approaches for the provision of safety critical services. In this case, the band 5 091-5 150 MHz may provide sufficient capacity for redundancies to comply with the particular requirements of safety critical communication applications.

5 General considerations

This report does not suggest any preferred method.

It is to be noted that according to the international convention on civil aviation, Annex 14 Part 1 it has to be ensured that the airport facilities meet the required specifications and that the operating authority can maintain these specifications. This standard, among other things, provides criteria for siting of antenna towers or other equipment that penetrates the restricted vertical zone surfaces.

It should be noted that, in the 5 091-5 150 MHz band, airport surface communication networks, based on either Method A or Method B topologies, will need to protect NGSO-MSS feeder links

⁶ The benefits on the spectrum requirements of a frequency reuse factor of 1 have not been addressed in the same manner in the existing (Nov. 2011) ITU-R deliverables dealing with the spectrum requirements for systems using technology similar to those considered in this report.

operating in the band. Recommendation ITU-R M.1827 and Report ITU-R M.2118 are relevant to this protection.

It is therefore necessary that either of the two Methods describe how the above mentioned protection is implemented, noting that the topology used in Method A is similar to that contained in Report M.2118, which could be considered as complying with objectives of the Recommendation ITU-R M.1827.

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Annex 1

1 Potential applications for the airport surface

Airport surface wireless systems could provide the means of transporting data in the airport environment. With terminals located on the ground, on taxiing aircraft, and on parking aircraft, the systems are envisioned to support short-range, high-data-rate applications. Data rate requirements are calculated for two phases: Phase 1 (2020) and Phase 2 (beyond 2020) [6]. These requirements are focused on communications supporting safety and regularity of flight.

The following potential applications have been identified, and their requirements, together with assumptions on the distribution of system participants, system channel structure and channel loading result in the bandwidth requirements contained in § 3.1 of this Report.

Applications

Category 1: Airport surface communications between aeronautical stations and aircraft stations

- Airport surface data for situational awareness;
- Video streaming;
- Voice over Internet Protocol (VoIP) over wireless;
- Aeronautical Operational Control (AOC) data, including Electronic Flight Bag (EFB) data;
- Radio-frequency identification (RFID) data;
- Airport Mapping Database (AMDB) data;
- Integrated Vehicle Health Management (IVHM) data;
- 4-dimensional weather data;
- Aircraft de-icing data;
- Services to support unmanned aircraft system (UAS) operations on the airport surface.

* Limited to aeronautical mobile telemetry for aircraft flight testing (referred to as AMT) and AMS for aeronautical security, and AM(R)S.

Category 2: Airport surface communications other than those in Category 1 above

- Surveillance data (radar data);
- Sensor data (video surveillance and Navigational Aids to Terminal Radar Approach Control (TRACON));
- Weather data (weather radar, Automated Weather Observing System – AWOS, etc.);
- TRACON/(non-collocated) Air Traffic Control Tower (ATCT) data.

Aircraft counts from a high-density (HD) airport are used in the analysis, and are shown in Table 5. Low-density (LD) airport aircraft counts are also included for information.

Figure 3 summarizes all the applications classes for airport surface communications.

FIGURE 3
Potential airport surface communications system applications

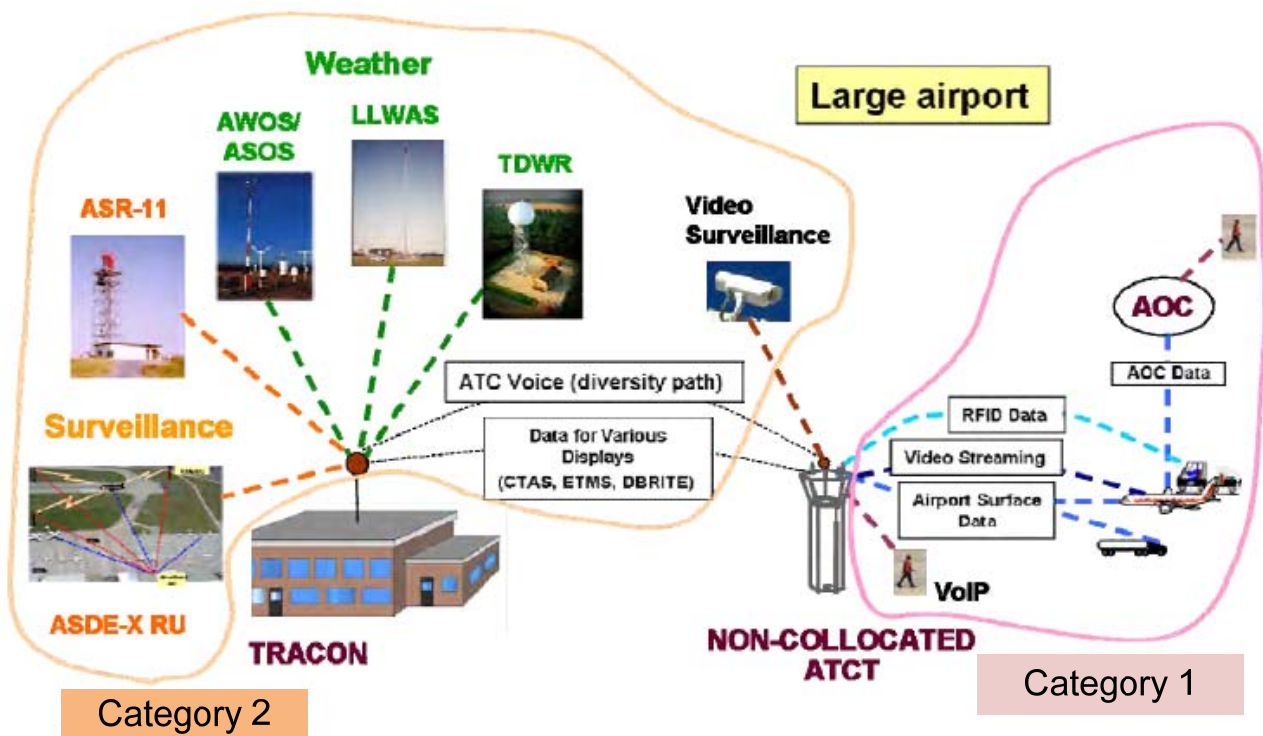


TABLE 5
Aircraft count

Airport position	Phase 1		Phase 2	
	HD	LD	HD	LD
Clearance/ramp	134	4	194	7
Tower	18	5	26	8
Ground	43	3	70	4
Total	200	12	290	19

Table 6 shows a summary of the potential application classes and their data rate requirements for the Phase 1 implementation, which is expected to be complete around 2020.

Table 7 shows a summary of the potential application classes and their data rate requirements for Phase 2 (beyond 2020) implementation.

TABLE 6
Summary of potential applications for Phase 1

Application class description	Estimated data rate (kbit/s)	Estimated maximum number per airport	Maximum estimated aggregate data rate per airport (kbit/s)
Applications in Category 1			
Airport surface data to aircraft	619.1	3	1 857.3
Video streaming	449.4	5	2 247
VoIP	23.4	45	1 053
AOC data (includes EFB)	9.0	200	1 800
RFID data	0.5	134	67
AMDB data	792.3	5	3 961.5
IVHM data (aggregate real-time)	2 974.7		2 974.7
IVHM data (stored)	111.7	154	17 217.2
4D weather data (agg addressed)	2 050.5		2 050.5
4D weather data (broadcast)	299.8	3	899.4
Aircraft de-icing data	281.9	2	563.8
Airport surface UAS	845.7	5	4 228.5
Total estimated data rate (kbit/s)*			38 919.4
Applications in Category 2			
Surveillance data (aggregate)			1 486
Sensor data (aggregate)			23 797.6
Weather data (aggregate)			2 158.5
ATC voice diversity path to remote Tx/Rx			6 312
TRACON/ACTC data (aggregate)			18 757.5
Total estimated data rate (kbit/s)*			52 511.6
Combined total estimated data rate (kbit/s)*			91 431

TABLE 7
Summary of potential applications for Phase 2

Application class description	Estimated data rate (kbit/s)	Estimated maximum number per airport	Maximum estimated aggregate data rate per airport (kbit/s)
Applications in Category 1			
Airport surface data to aircraft	619.1	3	1 857.3
Video streaming	449.4	7	3 145.8
VoIP	23.4	45	1 053
AOC data (includes EFB)	41.0	290	11 890
RFID data	2.2	194	426.8
AMDB data	1 188.4	7	8 318.8
IVHM data (aggregate real-time)	4 259.5		4 259.5
IVHM data (stored)	157.5	222	34 965
4D weather data (agg addressed)	4 455.3		4 455.3
4D weather data (broadcast)	299.8	3	899.4
Aircraft de-icing data	281.9	2	563.8
Airport surface UAS	845.7	7	5 919.9
Total estimated data rate (kbit/s)*			77 754.8
Applications in Category 2			
Surveillance data (aggregate)			1 486
Sensor data (aggregate)			23 797.6
Weather data (aggregate)			2 158.5
ATC voice diversity path to remote Tx/Rx			6 312
TRACON/ACTC data (aggregate)			18 757.5
Total estimated data rate (kbit/s)*			52 511.6
Combined total estimated data rate (kbit/s)*			130 266.2

* The airport surface data transmission is envisioned to be implemented by using the broadcast/multicast features of the IEEE 802.16e Standard. For the 20 MHz channel bandwidth case, it is assumed that the base stations would use omnidirectional antennas. For the 10 MHz channel bandwidth case, it is assumed that the base stations would be sectorized (with three sectors for each base station). For sectorized base station antennas that airport surface data would be transmitted in each sector, so higher data rate requirements (an increase of $2 \times 1\,857.3 + 2 \times 899.4 = 5\,513.4$ kbit/s) are obtained for the 10 MHz channel bandwidth case in both phases.