ENHANCING THE "LAST MILE" COMMUNICATIONS AT AIRPORTS

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Abstract

With the predicted increase in air travel, airports worldwide are modernizing to improve their state and performance. This paper focuses on how the "last mile" communications at airports, i.e., aircraft communications when on the airport surface, benefits this modernization. Networking and information technology provide opportunities to reduce flight delays and turn times on the airport surface. However, effectively managing airport networks is a novel challenge, due to new operational constraints and requirements. Additionally, as aircraft become smarter and tightly integrated with airports, they will rely on the availability of high bandwidth connectivity to airport-based systems for refreshing and retrieving digital content. This paper proposes a framework to understand the challenges to the design of network management solutions. Furthermore, solutions to enhance the bandwidth, resilience, and robustness of last-mile connectivity link at airports are presented.

1 Introduction

A major challenge for future airspace systems is safely, efficiently, and economically managing the predicted air travel growth. Adding to this challenge is the increasing complexity of the operational environment due to evolving societal and economical demands, aging infrastructures, and persistent adaptive threats from nature and humans. Airspace systems worldwide are transforming today to meet future aviation demands [1].

Airport is the most utilized infrastructure in the airspace system today. However, it presents a major performance bottleneck for aviation; e.g., contributes 85% of the average gate-to-gate flight delay in the USA [2]. Several efforts are defining the way future airports will shape (e.g., structures and interiors) and operate (e.g., safe and secure flow of passengers and cargo).

Data networks are a key technology in the operational modernization of airports. Apart from catering to the increasing communication demands of passengers and airport businesses, data networks provide opportunities to enhance the quality and level of information sharing between systems and stakeholders at airports; thereby, helping to assure and maximize operational performance of future airports.

Airport data networks can be spatially categorized into land side, terminal area, and air side (or airport surface area) networks. Land side and terminal area networks primarily focus on improving services to the passenger, as he/she interacts with processes and facilities at airports and airlines [3]-[4]. Surface area network provides the "last mile" connectivity and mobility critical for aircraft operating at the airport (see Fig. 1). This "last mile" integration between the aircraft and its airport promises to reduce scheduled flight periods as well as flight delays at gates, taxiways, and runways. This paper we focus on airport surface networks.

Most existing works on airport surface area networks address wireless networking issues, such as wireless spectrum choices, network coverage, radio channel, and signal interference models [5]-[6]. However, there is lack of a clear understanding of the issues with managing airport surface area network and enhancing "last

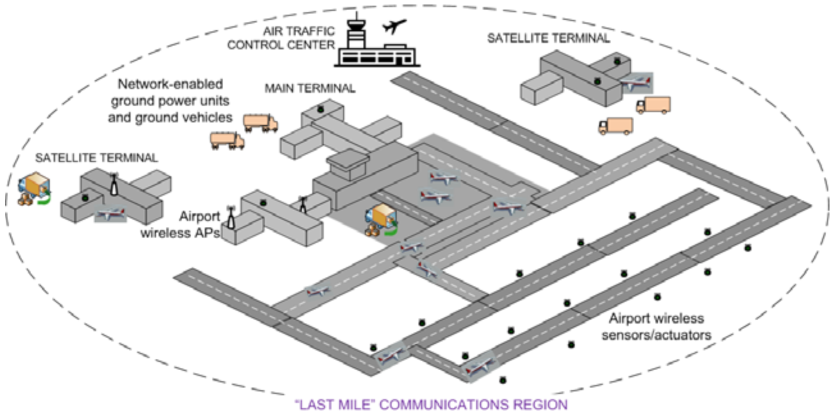

Fig.1. Illustration of a future net-enabled airport (air side) with e-enabled aircraft and other wired/wireless nodes.

mile" connectivity of aircraft. This paper bridges these research knowledge gaps in enhancing future airport performance.

1.1 Our Research Contributions

- We propose a comprehensive framework for understanding airport surface area networks. The framework helps identify opportunities, challenges, and risks posed by networks to the airport system performance. We discuss preliminary work on policy-based solutions to control performance of airport network.
- We address the problem of enhancing the "last mile" communications of aircraft, i.e., providing broadband communications to individual aircraft, by investigating the beneficial use of advances in WiFi, WiMAX, 3G/4G cellular and power line communications technologies.

1.2 Paper Outline

Section 2 describes a future airport networked system model with the e-enabled aircraft. Section 3 presents the proposed framework for understanding airport surface area networks. Section 4 compares different off-board communication technology choices for "last mile" connectivity at airports, proposing a way forward for enhanced off-board communications. Section 5 discusses issues, our ongoing work, and lists some open problems. Section 6 concludes the paper.

2 Future Airport Networked System: AWIN

Advances in data networking and information technology will together transform the airport to a net-centric aviation ecosystem. This ecosystem is a heterogeneous mix of mobile and fixed network entities operating in a harsh natural and artificial environment at the airport (see Fig. 1). The classes of network users considered in this system include:

- Networked aircraft at the gates, taxiways, runways, and terminal airspace of the airport.
- Fixed networked systems for performing flight control and cabin operations, e.g., systems of the air traffic control tower and airlines operations center.
- Mobile networked surface vehicles for airlines and aircraft services, e.g., passenger transit vehicles and fuel, catering, baggage and fire fighting service vehicles.
- Ubiquitous devices brought-in by crew in the cabin for performing aircraft maintenance, e.g., a wireless laptop for distributing avionics software.
- Ubiquitous devices carried by crew on the tarmac for performing aircraft maintenance, e.g., a wireless laptop for diagnosing aircraft hardware parts.
- Fixed sensors for airport ground operations and maintenance. For example, sensors controlling runway/taxiway lights, cameras for monitoring gates, airport weather sensors.
- Human operators, including flight deck, airlines, airport, and air traffic control crew.

Hereon, we refer to this heterogeneous airport wireless/wired networked system as the AWIN. The AWIN is expected to offer year-around availability of a reliable network for exchanging diverse administrative and operational information on the surface of the airport – which can be an area of a few miles (say 5-10 miles) in diameter and up to thousands of feet (say 3000-5000 feet).

In the AWIN, *aircraft-to-ground* links allow networked aircraft to tightly integrate with airport systems (shown in Fig. 2). Aircraft can exchange information with the air traffic control (ATC) facilities, airline systems, as well as vehicles and ubiquitous devices located on the airport surface. For example, dedicated aeronautical communications for navigation, surveillance data and voice exchanges with ATC systems; aircraft taxing, gate status, operational updates, maintenance, hazardous cargo, and de-icing data with airlines systems, airport vehicles, and crew devices.

However, in this paper we do not further cover air traffic control specific aircraft-to-ground data links, such as ADS-B and ACARS, due to their relevance to all phases of flight.

AWIN also enables *ground-to-ground* links on the airport surface (not shown in Fig. 2) resulting in a close integration and coordination of airport ground facilities. For example, by connecting airport surveillance radars and ADS-B stations to the air traffic control tower, or connecting vehicles and fixed sensors on the surface to centralized airport systems.

2.1 Future E-Enabled Aircraft at Airports

The e-enabled aircraft is a recent vision is commercial aviation of a networked aircraft that participates as an intelligent node in a global information network of airborne, space, and ground systems. Seminally instantiated by the Boeing B787, the e-enabled aircraft realizes unparalleled opportunities for enhancing flight and connecting stakeholders with aircraft [7].

The future e-enabled aircraft will further promise to tightly integrate with off-board systems for seamless mobility and enhancing airspace system performance [8]. On airport surfaces the future e-enabled aircraft can readily

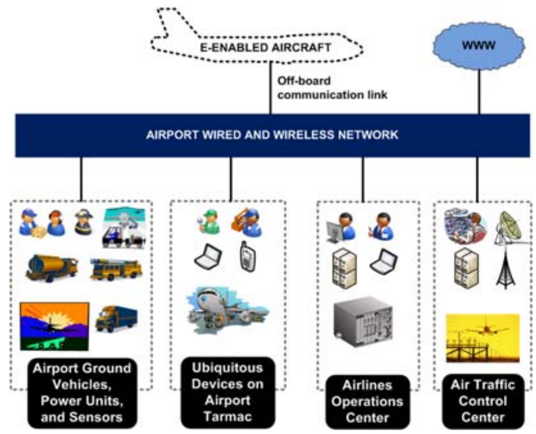

Fig. 2. E-enabled aircraft and interacting entities at net-enabled airports.

connect to the AWIN and communicate with the airline systems for refreshing avionics software and exchanging big data. For example, an end-to-end information flow for distribution of avionics software from suppliers to airliners includes the remote airline back office server, Internet, with the AWIN providing the critical "last mile" communications to the aircraft [9]. Furthermore, the future e-enabled aircraft can readily participate in emerging networks in AWIN that aim to improve surface operations.

With increasing network and information technology based aeronautical capabilities and airline applications, the aircraft digital content size is expected to substantially increase. Most of this content will need quick and regular refresh and retrieval by aircraft stakeholders. Furthermore, the tight integration between aircraft and off-board systems is anticipated to significantly increase the frequency and volume of aircraft-to-ground information exchanges. These forecast trends indicate the reliance on airport surface network to provide reliable high-bandwidth last mile communications. Managing the AWIN and enhancing last mile connectivity of aircraft, hence, is extremely critical for future airport performance.

3 Proposed Framework for AWIN

This section provides a framework to understand the different challenges and constraints involved in managing the AWIN.

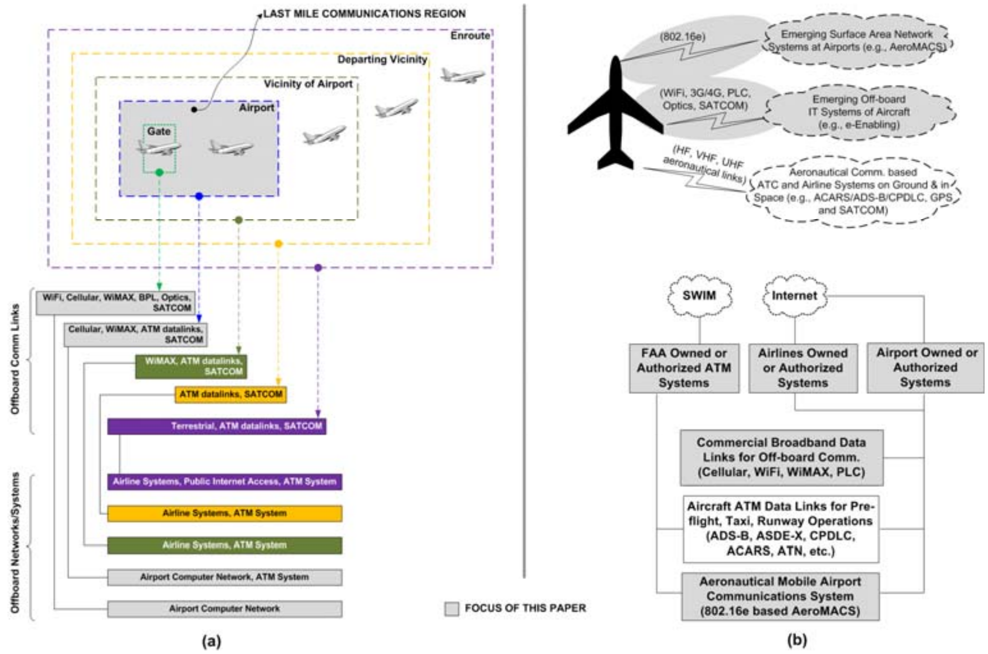

Fig. 3. (a) Aircraft communications and their relation to flight phases. (b) Aircraft communications with ground/air/space systems and system owners at airports.

3.1 System Applications

Based on the type of information assets exchanged over the AWIN, we can classify the network applications as flight control, flight operations, flight logistics, aircraft health management, and aircraft ground operations.

- **Flight Control:** Using ground-to-ground links in the AWIN, air traffic information assets received by navigational/surveillance facilities in the immediate vicinity of the airport, such as radars and ADS-B stations, can be seamlessly communicated to the airport traffic control tower. Example of transported information assets include ADS-B data, multilateration results, radar readings, flight advisory and instructions data, and flight and traffic information services data. Safety-critical tasks of the aircraft depend on these assets, such as aircraft separation, approach-and-landing, departure, etc.
- **Flight Operations:** Using aircraft-to-ground links in the AWIN, pilots and embedded aircraft modules can communicate with the airlines operations center (AOC) systems for effectively and efficiently performing flight tasks. The transported information assets are a mix of safety assured, non-safety-critical and proprietary assets. Some examples include the update and data for maintaining airplane software configuration (i.e., RTCA DO-178B Level A – E software), electronic flight bag (e.g., flight plan and weather data), and in-flight entertainment content (e.g., multimedia and first-run movies).
- **Flight Logistics:** Aircraft-to-ground links in the AWIN also enable cabin crew and onboard RFID systems to communicate with the networked ground systems for timely management and tracking of aircraft inventory, parts and payload. The transported information assets can be considered to be business-critical or private in nature. Cabin crew information asset examples include passenger lists and credit card transactions data, which must be verified and validated per flight. The RFID information asset examples include data on onboard passenger baggage, cargo, LRUs, vests, etc, which must be monitored and recorded per flight.
- **Aircraft Health Management (AHM):** Aircraft-to-ground links in the AWIN also enable structural and engine health

monitoring sensory systems on aircraft to communicate with ground personnel devices, as well as offer the first communication hop for remote systems of airlines and equipment suppliers, to enable the next-generation condition-based aircraft maintenance. Transported information assets are considered business-critical and/or proprietary.

- **Airport Ground Operations:** Both ground-to-ground and aircraft-to-ground links can enable fixed ground sensors, mobile vehicles and ground personnel to communicate with airport-based systems as well as with aircraft systems to safely as well as efficiently control surface operations. For instance, runway light, airport weather and tarmac video sensors can be remotely accessed and controlled for enhanced safe aircraft operations on the surface and tarmac. Fuel, catering and passenger transit service vehicles and personnel can use wireless access for enhanced situational awareness and informed decision making. Fire and other rescue vehicles can receive ground surveillance information while en-route to the accidence scene at the airport, for effective and prompt response. Airport surface maintenance activities can be coordinated with the air traffic control tower and aircraft. While most of the information assets are considered to be non-critical, some may be considered to be private data such as identities of passengers in transit vehicles.

3.2 System Goals

Based on these applications, we can broadly state goals of the AWIN as:

- **Safety enhancement:** The system must preserve or enhance safety of all entities at the airport and the surrounding population.
- **Flight regularity:** The system must reduce or minimize flight delays, disruptions and cancellations.
- **Business profitability:** The system must reduce or minimize any unwarranted costs, reputation damages, and personal and intellectual property losses for stakeholders and users.

3.3 System Constraints

The AWIN presents unique constraints to the design of network management solutions. These are given below; Table 1 shows application classes impacted by the identified constraints.

- **Regulatory needs:** Applications may depend on the availability of wireless channels to deliver assets that are defined as safety-critical by current federal regulations and guidance for aviation. In such cases, availability of the wireless network must be safety assured. This need for safety assurance is new to wireless communications. Furthermore, existing well-defined safety regulations based constraints are expected to be prevalent for the AWIN, such as the assured network separation of onboard critical systems from the Internet at all times of flight [9].
- **Lean operational/management overhead for airlines:** Airlines are today faced with increasingly tight schedules and constrained budgets that allow room for only reduced costs and error margins in fleet operation.
- **Multiple domain users:** The AWIN will be accessed by various parties jointly involved with the safe and profitable aircraft operation and maintenance. These include the airlines hired or contracted servicers responsible for maintaining software and hardware configurations, contracted third parties responsible for airport services such as baggage handling, fuel supply, catering and other cabin inventory providers, and airport ground services such as maintenance of runway/taxiway, etc. Hence, solution interoperability across multiple domains is essential.
- **Co-existing wireless networks at airport and aircraft:** The airport includes wireless networks operated by third parties and used by passengers, airport consumer services, etc. Future aircraft will have multiple wireless access points onboard, for example,

Constraint / Application Class	Flight Control	Flight Operations	Flight Logistics	AHM	Airport Ground Operations
1. Regulatory needs	×	×	×	×	
2. Lean overhead for airlines		×	×	×	
3. Multiple domain users	×	×	×	×	×
4. Co-existing wireless networks		×	×	×	×
5. Type, number and size of assets	×	×	×	×	×
6. Broadcast communications	×				×
7. Variable transmission range		×	×	×	
8. Multi-hop communications			×	×	×
9. Aircraft network connectivity		×	×	×	
10. Node heterogeneity	×	×	×	×	×
11. Existing infrastructures/procedures	×	×	×	×	×
12. Node mobility	×	×	×	×	×
13. Airport types	×	×	×	×	×
14. RF Antenna Types		×	×	×	×

Table 1. Impact of constraints on identified system applications. × denotes there is impact.

third party access points providing Internet access to onboard passengers.

- **Type, number and size of assets:** Transported assets can be: *non-critical* if they do not impact the system goals (e.g., periodic weather reading from a ground sensor); *business-critical* if they impact flight regularity and business profitability goals (e.g., updates on cabin inventory); and, *safety-critical* if they impact safety enhancement goals (e.g., system-down feedback from runway light sensors). The level of protection needed can hence vary with the criticality of applications/systems in the AWIN. Furthermore, the volume of data from a networked node may vary in the AWIN (e.g., a weather sensor or video sensor compared to a runway light sensor).
- **Broadcast communications:** Some types of information may benefit multiple entities in the AWIN, hence making the use of broadcast cost-effective and time-efficient.
- **Variable transmission range:** Airlines as well as other parties at airports will benefit from communicating with aircraft as soon as (or until) the aircraft enters weight-on-wheels (weight-off-wheels) condition. Some applications therefore may benefit from the aircraft varying their one-hop transmissions to reach airport terminal located systems.
- **Multi-hop communications:** At the same time, due to some RF communication impeding physical structures as well as distributed nature of operations at the airport, ad hoc mode of network operation can serve as a more reliable model for some of the AWIN applications. In such cases, an end-to-end communication may consist of two or more entities with one ore more routers. While ad hoc networking presents vulnerabilities (such as in routing, etc.), it also provides redundancy (such as in routes available) to provide better reliability and availability assurance for AWIN.
- **Aircraft network connectivity:** In AWIN, network access to onboard systems can be time limited, e.g., only during weight-on-wheels. Airborne connectivity at airport surfaces can be intermittent due to aircraft mobility and radio interruptions.
- **Node heterogeneity:** The AWIN has a variety of networked nodes that can vary in

their memory, energy, processing and communication capabilities. For instance, energy resources decrease as we move from airplanes to surface vehicles to handheld devices to low-cost sensors. Physical and remote access to these nodes varies based on the location and purpose of these nodes at the airports.

- **Existing infrastructures and procedures:** Airports and aircraft have well-established processes and means of operation and maintenance at airports, some potentially yet to meet the return-of-investment. These present leverage opportunities as well as reverse compatibility solution constraints.
- **Node mobility:** Mobile nodes will exhibit speeds that range from zero to surface vehicular speeds to airborne vehicular speeds. In addition, pedestrian speeds will also be observed. Completely static nodes are also involved in the AWIN, such as the fixed sensors on the ground and fixed wireless base stations at the airport, radars, etc. Furthermore, surface vehicles are limited in their movement at the airport, in terms of restricted area of operation, etc. The aircraft are also restricted in how they move in tarmac, taxiways and runways.
- **Airport types:** Each airport belongs to a specific class of physical layout design – defined by its terminal structure (e.g., main terminal and satellite terminals), and locations of gates, ramps, tarmacs, taxiways and runways – and has its own configuration and operational needs. So each airport warrants unique considerations for solution design and implementation.
- **RF antenna types:** Omni-directional as well as sectorized antennas are being planned to cover, with minimal RF interference, different regions of the terminal, gates, ramps, tarmacs, taxiways, runways and immediate vicinity of an airport.

Overall, the above constraints exemplify the unique challenges that will test the design of network management solutions for the AWIN. Identifying potential network management solutions for the AWIN will be considered in our future work.

4 Enhancing Off-board Communications

4.1 Wireless Technologies

- **WiFi (IEEE 802.11a/b/g/n)**: WiFi has promising features for deployment at airports, especially due to the wide adoption and the low cost deployment of wireless access point (AP). In addition to its low cost deployment and ubiquity, WiFi technology has matured and become commercially viable. Recently WiFi is tested in the IEEE 802.11 based DSRC (Dedicated Short-Range Communications) link for automotive vehicular ad hoc networks and in low-power sensor networking. Hence, WiFi currently provides the most feasible off-board wireless communications link that can in the long term benefit the AWIN.
- **WiMAX (IEEE 802.16)**: WiMAX (Worldwide Interoperability for Microwave Access) is based on IEEE 802.16 and is intended for wireless metropolitan area networks. WiMAX has longer range wireless communication than WiFi. These advantages have resulted in the ongoing effort to dedicate a WiMAX C-band spectrum (5091-5150 MHz) for the Aeronautical Mobile Airport Communications Systems (AeroMACS) [8].
- **Cellular (3G/4G)**: As a candidate for the off-board communication at airport between aircraft and ground systems, the cellular technology has advantages including a well-established infrastructure and potential for worldwide network coverage. At the same time, some of the major concerns include potential bandwidth limitations and costs.
- **Satellite Communications (SATCOM)**: Satellite communication is the primary communication means existing for in-flight aircraft. The advantage of satellite communication is its global seamless coverage, including over oceanic and remote areas. Major challenges with SATCOM use is the operational costs and return-of-investment.
- **Satellite Communications (SATCOM)**: Satellite communication is the primary communication means existing for in-flight

Technology / Security Requirement	WiFi (802.11i)	WiMAX (802.16e-2005)	Cellular (3G)
Encryption	WPA2: AES-CCMP	AES or 3DES (128 or 256 bit key)	Stream & Block ciphers
Authentication	AAA/EAP user Auth.	X.509 certificate supported (public key based) device auth (one-way); EAP-TLS based user auth (two-way).	USIM card (symmetric key) based user auth. Mobile terminal's IMEI number verified.
Availability	Operated in unlicensed band vulnerable to jamming	Operated in licensed band, relatively easier to detect jamming	Subject to jamming (high power needed to jam a BS)
Anonymity	Not addressed	Not addressed	Temporary ID

Table 2. Comparison of security features of wireless technologies.

aircraft. The advantage of satellite communication is its global seamless coverage, including over oceanic and remote areas. Major challenges with SATCOM use is the operational costs and return-of-investment.

4.2 Wired Technologies

- **Power Line Communications (PLC)**: PLC is a system for carrying data on a conductor also used for electric power transmission [7]. Broadband over Power Lines (or BPL) uses the existing power grid infrastructure to provide high-speed, broadband network link for aircraft. BPL offers an attractive off-board communication link since it does not require additional infrastructure investment due to existing power line infrastructure and it is a physically protected communication link. Major challenges are potential physical layer noise from natural signaling disruption and power systems interference, and need for expensive repeaters if communications extends through transformers.
- **Optical Fiber Communications**: Optical fiber communication is any form of telecommunication that uses light as the transmission medium. An optical communication system consists of transmitter for encoding to an optical signal, channel, and receiver for decoding the signal [9]. Advantages include resilience to electromagnetic inference when compared with conventional copper wire. However, major challenges exist with costs and effort needed for deploying fiber cables.

4.3 Comparison of Wireless Technologies

A major challenge with commercial wireless data links are security threats and emerging vulnerabilities. These present risks to the availability and reliability guarantees of the wireless connections in the AWIN. Fortunately, wireless community has actively addressed security issues in the past few years. Table 2 provides a high-level summary of some current state-of-the-art solutions employed to protect data confidentiality, integrity, availability, and anonymity, in general WiFi, WiMAX, and cellular network applications.

4.3 Potential Enhancement Approach

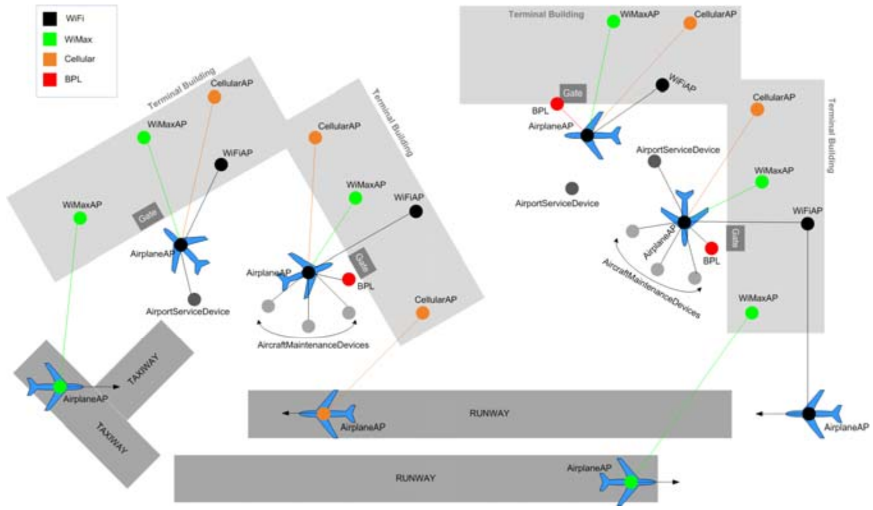

Fig. 4. Illustration of multiple aircraft off-board communication links at airport.

Based on our ongoing investigation, we observed that no single technology can potentially address all AWIN needs/constraints, security and cost considerations, and bandwidth needs. Hence, as shown in Fig. 4, it can be anticipated that future airports may host a mix of WiFi, WiMAX, cellular, satellite, and PLC technologies for high-bandwidth last mile connectivity. Such a network setup can enable the AWIN to provide robust, resilient exchange of increasing volume of aircraft information assets on the airport surface (see Fig. 5).

5 Discussion and Open Problems

5.1 Emerging Standards

RTCA SC223 and the EUROCAE WG82 committees are jointly coordinating to develop international standards that apply to airport surface wireless networks. The system model considered by SC223 is a large-scale and complex model that includes different stakeholders and mobile users in airport environment, as well as the different types of applications/services based on aircraft-to-X (where X can be aircraft, ground vehicle, or a fixed system), vehicle-to-vehicle and fixed-to-fixed system exchanges at the airport surface. On the other hand, the WG82 considered system model appears to primarily include aircraft-to-fixed system exchanges and facilitate Air Traffic Services (ATS) and AOC applications. The AWIN covers both SC223 and WG82 system models.

5.2 Airport Network Policies

Network policy specification enables definition of policy statements from applicable rules, regulations and requirements. Policy management typically includes monitoring and ensuring policy compliance, recording any policy compliance/non-compliance, and reviewing/updating policies. Policy verification is complimentary to these two areas, focused on testing if a given policy is correct and complete. To the best of our knowledge, the state-of-the-art includes policy specification and verification methods as well as policy management frameworks, but mostly for enterprise networks and some SCADA systems [9]. However, the future airport will present a unique environment that is different from enterprise and traditional SCADA environment. New network policies and policy management frameworks are needed for such intelligent networked airports.

Ongoing efforts develop network management systems for airlines at airports [6]. Airlines can monitor and manage network applications of their aircraft fleet at airports. Most of these efforts do not yet consider the need for policies to assure performance of airport network and airline applications. Our preliminary work addresses this gap [9].

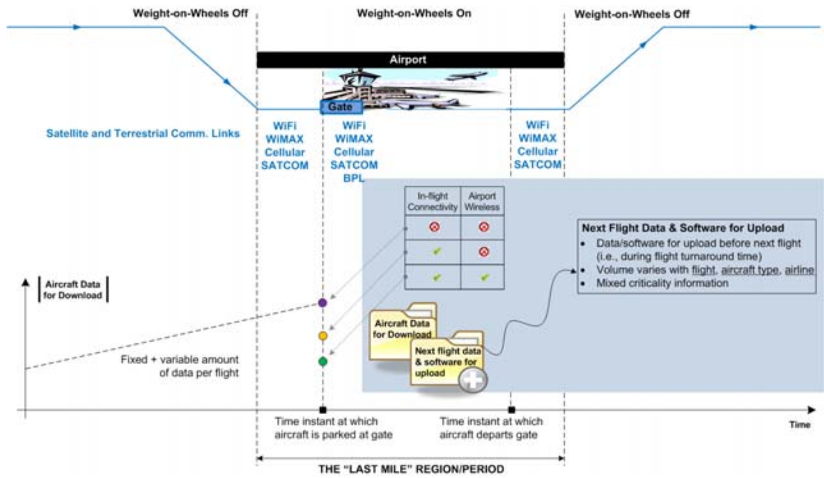

Fig. 5. Illustration of increasing data volumes in the last mile region/period.

6 Conclusions

Airports present unique challenges to the use of such commercial-grade wireless/wired broadband technology because of unique properties, such as regulatory constraints, mixed criticality of information assets, year-around network availability, and diversity in network users and devices. Furthermore, network performance requirements such as reliability, availability, timeliness, security are more stringent for airports compared to traditional enterprise network applications. Wireless disruptions and loss may have larger impact on the airport network applications and users due to the potential direct impact on flight regularity, airline/airport business and passengers. We discuss these aviation-specific challenges, and propose some promising solution approaches that can address them. In the future work, we will address the performance risks that emerge from natural and intentional disruptions in the airport surface networks.

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