Commonwealth of Virginia
Enterprise Technical Architecture [ETA]

Wireless Radio Communication

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Executive Summary

This technical brief discusses:

- Wireless communication technology used to connect computers, tablets, smartphones and other devices to the internet, and
- Wireless Access Points (WAP), hardware devices that enable wireless capable devices and wired networks to connect through a wireless standard, including Wi-Fi or Bluetooth.

It is the summary recommendation of this brief that current mainstream Wi-Fi implementations prefer Wi-Fi 5, using devices that support the IEEE 802.11ac and 802.11ad standards. However, the recent availability of Wi-Fi 6 and Wi-Fi 6E devices supporting the 802.11ax standard means that COV agencies will soon be able to leverage the enormous potential of the 6 GHz radio spectrum, and should consider this when planning new infrastructure implementations or upgrades.

Background

Wireless communication focuses principally on three areas:

- Cellular networking, for transmission of voice, data, and other content
- Wi-fi for local area networking of devices and internet access
- Internet of Things (IoT) for use of physical objects or devices embedded with sensors that exchange data with other devices and systems over the Internet or other communications networks

Rather than being mutually exclusive, these uses frequently overlap, providing technical solutions for a variety of use cases, many times within the same device. This condition is observed in the majority of smartphones available today.

Figure 1 — Apple iPhone 12

The Apple iPhone 12 smartphone, for example, communicates across several different radio bands:

- Cellular 4G LTE, 5G
- Wi-Fi, tri-band 2.4, 5, and 6 GHz
- Bluetooth 5.0

- Global positioning, GPS[1], GLONASS[2], Galileo[3], QZSS[4], and BeiDou[5]
- Near Field Communication (NFC)

Figure 2 — Samsung Galaxy Fold 3

This complexity is not limited to smartphones as computing devices become more sophisticated, with increasing impact on the business environment. The Samsung Galaxy Fold 3, for example, is a cellular-enabled tablet that targets commercial customers as a convergence device, a smartphone, tablet, and PC rolled into one. It is no less featured than the iPhone in its capabilities to communicate across multiple platforms.

- Cellular, LTE / 5G
- Wi-Fi 2.4, 5, & 6 GHz
- Bluetooth 5.0
- Global positioning, GPS, GLONASS, Galileo, BeiDou
- Near Field Communication (NFC)

Figure 3 — Wireless building communication

Further complicating the landscape is the burgeoning use of sensors and devices to manage buildings, which also communicate using wireless protocols. Building automation encompasses a wide range of services, including HVAC controllers and air quality systems, lighting and signage, security and access

[1] Global Positioning System (GPS), United States
[2] Global Navigation Satellite System (GLONASS), Russia
[3] Galileo, European Union
[4] Quasi-Zenith Satellite System (QZSS), Japan
[5] BeiDou Navigation Satellite System (BDS), China

control, energy management and metering, elevators, networked equipment, and other building systems.

Figure 4 — Wireless wearable devices
Left — Logitech H800 Bluetooth Wireless Headset; Right — Apple Watch Series 3 GPS

Moreover, the presence of wireless wearable devices in the workplace also adds to the density of the radio spectrum. Whether it is the use of Bluetooth or Wi-Fi enabled mice, headsets for conferencing, or smart watches paired with a wearer's smartphone, they add to the volume of signal traffic. The increase of radio connectivity brings with it a high potential for conflicts and collisions between competing devices, and degradation of service due to use of specific radio bands, especially those consumed by Wi-Fi.

Wi-Fi

The story of Wi-Fi starts in 1985, with the FCC's release of the ISM band, a portion of the radio spectrum reserved internationally for industrial, scientific and medical purposes, for unlicensed use. A corresponding rise in use of computers for common business applications led to a search for solutions for wireless access.

This culminated in the creation of the 802.11 standard by the Institute of Electrical and Electronics Engineers (IEEE) in 1997, defining communication for Wireless Local Area Networks (WLANs). This sparked development of routers to comply with IEEE 802.11, and in 1999, Apple introduced the first mass consumer product with Wi-Fi for home use with their iBook laptop series and AirPort wireless routers and cards. IBM followed one year later with its ThinkPad 1300 series in 2000, leading the rest of the industry to quickly consolidate on Wi-Fi for wireless communication.

IEEE Standard	Generation	Throughput	Adopted	Frequency
802.11	Wi-Fi 1	2 Mbps	1997	2.4 GHz
802.11a	Wi-Fi 2	54 Mbps	1999	5 GHz
802.11b	Wi-Fi 2	11 Mbps	1999	2.4 GHz
802.11g	Wi-Fi 3	54 Mbps	2003	2.4 GHz
802.11n	Wi-Fi 4	600 Mbps	2008	2.4/5 GHz
802.11ac	Wi-Fi 5	3200 Mbps	2014	5 GHz
802.11ad	Wi-Fi 5	7000 Mbps	2016	2.4/5/60 GHz
802.11ax	Wi-Fi 6	9608 Mbps	2019	2.4/5 GHz
802.11ax	Wi-Fi 6E	9608 Mbps	2019	6 GHz

Figure 5 — Wi-Fi Generations

802.11 communicates at 2.4 GHz, which has three distinct benefits:

- it is the only radio frequency that is unlicensed globally
- it allows devices to be farther away from a router or wireless access point, and
- it is able to penetrate solid objects.

General adoption across an expanding array of different products—microwaves, baby monitors, garage door openers, and Bluetooth devices—quickly overcrowded the band, leading to degradation of service and dropped connections due to conflicts between devices.

Introduced in 1999, 802.11a extended Wi-Fi to the 5 GHz band, providing a number of advantages. With fewer competing devices operating in the spectrum, it is less prone to interference and congestion. It has 17 working channels, as opposed to the 13 in the 2.4 GHz band — resulting in higher stability and connection speed — and transmits data at a higher rate.

The intervening 20 years have seen succeeding Wi-Fi standards that maintain a balance between the strengths and weaknesses of these two bands. A 2.4 GHz connection travels farther at lower speeds, while 5 GHz frequencies provide faster speeds at shorter range, supporting the use of 5 GHz for devices closer to the router (25–35 ft) and 2.4 GHz for device farther from the router (75–100 ft).

Figure 6 — Dual band wireless router

The need to support both bands led to the development of dual-band routers, containing two of wireless radios that could simultaneously support connections on both 2.4 GHz and 5 GHz links. This allows a device to connect automatically to the faster, more efficient 5 GHz frequency by default, switching to the 2.4 GHz band as it moves away from the router, or is blocked by walls.

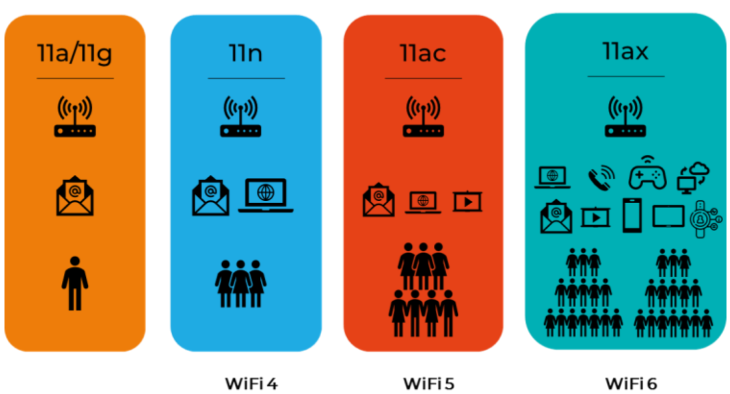

Figure 7 — Wi-Fi data transmission increases

Succeeding Wi-Fi standards have seen increases in throughput capacity. In 2009, 802.11n was the first to use the Multiple-Input-Multiple-Output (MIMO) method for communication, using multiple transmission and receiving antennas to increase the capacity of the radio link. Called Wi-Fi 4, the first branded Wi-Fi standard, it provided 11 times the capacity of its predecessor with 600 mbps of throughput. This trend continued with Wi-Fi 5, first with 802.11ac in 2014, which delivered 3200 mbps of capacity, and 802.11ad in 2016, which made it possible to deliver up to 7000 mbps on the 60 GHz band as well as 2.4 GHz.

Figure 7 — TP-Link - Archer 3200 Tri-Band Wi-Fi 6 Router

In 2020, the FCC opened the 6 GHz band for unlicensed Wi-Fi operations, releasing 1,200 MHz of additional bandwidth for commercial use. Not only is this a three-fold increase in the volume of available spectrum—a significant leap over the 70 MHz and 750 MHz provided by 2.4 GHz and 5 GHz respectively—it is free from both congestion and the potential for collisions due to its sheer size. The latest Wi-Fi standard, 802.11ax or Wi-Fi 6/6E, is poised to take advantage of this space, prompting the development of a new generation of devices capable of communicating in the 6 GHz band.

Internet of Things (IoT)

In parallel with the emergence of Wi-Fi has been the development of other wireless radio protocols to support the Internet of Things (IoT), the network of physical objects embedded with sensors, software, and other technologies for the purpose of exchanging data with other devices and systems over the internet. In the context of the workplace, IoT is most evident in building automation and Enterprise IoT.

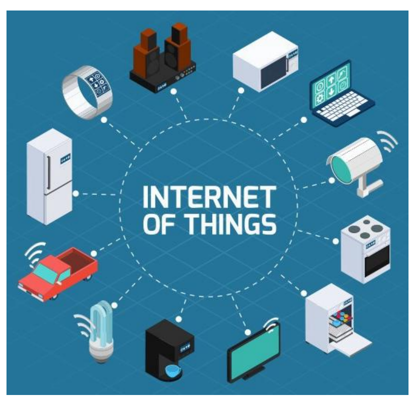

Figure 8 — IoT devices

Building automation is automated management of a building's control systems, everything from heating and air conditioning, lighting, and shading to access control and security systems. These can be independent, or part of a larger Building Management System (BMS) or Building Automation System (BAS), producing more efficient operation of systems and reduced operations and maintenance costs. The endless variety of available products in this space is supported by a similarly varied number of wireless protocols, notably ZigBee[6] and Z-Wave[7], but also including many other players such as 6LoWPAN, Dash7, Digimesh, EnOcean, Weightless, and others.

Enterprise IoT covers business and corporate devices used in settings, estimated to account for 12.3 billion devices in 2021. Here, the impact of embedding commodity sensors in devices to support business processes goes well beyond the familiar smartphones, smart screens, and smart speakers. Practical solutions exist across a broad set of domains of interest to the Commonwealth, particularly in medical and healthcare settings, or Vehicle-to-Everything (V2X) communications and Connected Cars. These devices are well supported by protocols such as Wi-Fi and Bluetooth, but include many others, such as ANT or 6LoWPAN.

Guidance Summary

The abundance of wireless protocols and their overlapping use of specific radio bands suggests care when planning or maintaining a Commonwealth work environment.

Frequency	Protocol
150 MHz-1 GHz	LoRaWAN
169 MHz	Weightless
433 MHz	Dash7 Weightless
470 MHz	Weightless
780 MHz	Weightless
868 MHz	Dash7 Weightless
900 Mhz	EnOcean SigFox Wi-Fi-ah
915 MHz	Dash7 DigiMesh Weightless ZigBee Z-Wave
<1 GHz	NarrowBand-IoT
1.4 MHz	LTE Cat-M1
2.4 GHz	6LowPAN ANT/ANT+ Bluetooth DigiMesh Ingenu mcThings MiWi Thread Wi-Fi 1-6 ZigBee
13.56 MHz	NFC

[6] An IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs.
[7] An open source 802.15.4-based protocol used primarily for home automation. It is a mesh network using low-energy radio waves to communicate from appliance to appliance,[1] allowing for wireless control of residential appliances and other devices, such as lighting control, security systems, thermostats, windows, locks, swimming pools, and garage door openers.

Frequency	Protocol
5 GHz	Wi-Fi 1-6
6 GHz	Wi-Fi 6
60 GHz	Wi-Fi 5

Figure 9 — Frequency consumption by protocol

The 2.4 GHz band is easily subject to clutter, due to its use by so many protocols. This can be offset by use of the 5 GHz band for devices that are not moved much and which can be located near a router, reducing congestion and taking advantage of higher speeds. Building automation protocols, which can operate in other frequencies, should prefer implementation in the other frequencies in order to reduce spectrum congestion.

This can be further improved through the use of Wi-Fi 5 and the 60 GHz band where the office plan supports its limited range, enabling the consolidation of the desktop with wireless docking stations, or streaming from laptops to smart devices or smart screens. The caution is that due to the limitations of the band and narrow use cases it supports, that routers supporting the frequency are likely to be more expensive than traditional dual-band routers. It also requires devices that can access the frequency, which excludes those manufactured prior to 2016 or which do not support 802.11ad.

The 6 GHz band also promises a solution to radio clutter, yet Wi-Fi 6E is so recent that the presence of Wi-Fi 6 clients and routers in the marketplace is low compared to those that support the 2 GHz and 5 GHz bands. Also, as with the 60 GHz band, devices are likely to be more expensive near term, requiring both routers and client devices that can access the band. However, agencies should anticipate the expansion of product choices and price reduction and begin planning and budgeting now for a transition to Wi-Fi 6E technology.

Finally, office space planning should consider the growing impact of wireless productivity devices used by COV employees. Headsets, smart phones, and smart watches, when paired with each other or with laptops, create Personal Area Networks (PANs)[8] which add to the consumption of the 2.4 and 5 GHz bands. Agencies may want to allocate additional WAPs in areas where PANs are expected to be most prominent, in order to reduce conflicts between competing devices.

[8] A computer network for interconnecting electronic devices within an individual person's workspace.

Appendix – Wireless Radio Protocols

Protocol	Frequency	Range	Data Rate	Power Draw	Topology	Hub/Gateway	Proprietary/Open	Implementation	Commercial Use
3G/4G/5G Cellular	700 MHz 800 MHz 850 MHz 1700 MHz 1900 MHz 2100 MHz 2300 MHz 2500 MHz	~20 miles	200 Kbps (3G) 30 Mbps (4G) 150 Mbps (5G)	High	Star	No	Open	WAN	Voice & data communication
6LowPAN	2.4 GHz	380 ft	250 Kbps	Low	Mesh	Yes	Open	Single Building	Home & building automation
ANT/ANT+	2.4 GHz	100 m	20 Kbps	Low	PAN	No	Proprietary	Personal	• Fitness tracking • Health monitoring
Bluetooth 4.0+	2.4 GHz	200 ft	25 Mbps	Medium	PAN	Yes	Open	Personal	Device connectivity
Bluetooth 5	2.4 GHz	800 ft	50 Mbps	Medium	PAN	Yes	Open	Personal	Device connectivity
Bluetooth Low Energy (BLE)	2.4 GHz	200 ft	10 Kbps	Low	PAN	Yes	Open	Personal	Device connectivity
Dash7	433 MHz 868 MHz 915 MHz	Up to 2 km	9.6 Kbps 55.55 Kbps	Low	Node-to-Node Star Tree	Yes	Open	WAN	• Home & building automation • Access control • Smart energy • Location-based services • Mobile advertising • Automotive • Logistics
DigiMesh	915 MHz 2.4 GHz	~20 miles	40 Kbps (915) 250 Kbps (2.4)	Low	Mesh	Yes	Proprietary	Single Building or WAN	Connecting time synchronized sleeping nodes/routers and low-power battery powered operation
EnOcean	900 Mhz	30-100 ft	125 Kbps	Battery Free	Mesh	Yes	Proprietary	Single Building	Home & building automation
Ingenu	2.4 GHz	~30 miles	624 Kbps	Low	Star	Yes	Proprietary	WAN	• Machine-to-Machine communication • Oil and gas field automation • Digital oilfield
LoRaWAN	150 MHz-1 GHz	up to 20 miles	50 Kbps	Low	Star	Yes/And	Open	WAN	Machine-to-Machine communication
LTE Cat-M1	1.4 MHz	~20 miles	1 Mbps	Low	Star	No	Open	WAN	• Smart meters • Asset tracking • Smart irrigation
mcThings	2.4 GHz	650 ft	50 Kbps	Low	Star	Yes	Proprietary	Single Building	Home & building automation

Protocol	Frequency	Range	Data Rate	Power Draw	Topology	Hub/Gateway	Proprietary/Open	Implementation	Commercial Use
MiWi	2.4 GHz subGHz	800 ft	250 Kbps	Low	Mesh or Star	Yes	Proprietary	Single Building or WAN	• Industrial monitoring & control • Home & building automation • Remote control • Wireless sensors • Lighting control • Automated meter reading
NarrowBand-IoT	Below 1 GHz	~20 miles	100 Kbps	Low	Star	No	Open	WAN	
NFC	13.56 MHz	~10 cm	424 Kbps	Low			Open		• Electronic identity documents • Keycards • Contactless electric payment
SigFox	900 MHz	~20 miles	100 Bps	Low	Star	Yes	Proprietary	WAN	Connect low-power objects such as electricity meters and smartwatches
Thread	2.4 GHz	100 ft	250 Kbps	Low	Mesh	Yes	Open	Single Building	Home & building automation
Weightless (W, N, P)	white-spaces 169 MHz 433 MHz 470 MHz 780 MHz 868 MHz 915 MHz	1.2 miles (P) 3 miles (W, N)	200bps-100Kbps	Low (N), Medium (W, P)	Star	Yes	Open	WAN	Machine-to-Machine communication
Wi-Fi	2.4 GHz 5 GHz 6 GHz	115-230	7 Gbps	High	Star	No	Open	Single Building	Data communication
Wi-Fi-ah	900 MHz	3000 ft	347 Mbps	Low	Star	No	Open	Single Building	
ZigBee	915 MHz 2.4 GHz	100-325 ft	40 Kbps (915) 250 Kbps (2.4)	Low	Mesh	Yes	Open	Single Building	• Home & building automation • Traffic management systems • Consumer & industrial equipment
Z-Wave	915 MHz	100-325 ft	40 Kbps	Low	Mesh	Yes	Proprietary	Single Building	• Wireless residential appliances • Home & building automation