The opportunities for wireless in hospital healthcare

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Contents

1 Introduction

Wireless connectivity technologies are evolving, driven by the development of the 5G and Wi-Fi 6 standards. Both bring a range of potential benefits, such as low power modes for Internet of Things (IoT), improved deterministic performance, and increased capacity and throughput. Furthermore, the convergence of next generation wireless communications, the IoT and artificial intelligence (AI) is enabling meaningful analysis of large volumes of distributed data in real time.

This comes at a time when healthcare systems across the globe have come under unprecedented strain from the COVID-19 pandemic, the long-term effects of which will be far-reaching. To respond to the crisis, hospitals have diverted clinical resources from their usual activities, resulting in cancellation and delays for millions of patients requiring surgical and other services around the world.[1]

Digital healthcare platforms have proven invaluable throughout the pandemic to keep services running and patients connected to healthcare providers while away from healthcare facilities. This is unlikely to be a temporary solution, with telemedicine expected to be embraced in many areas of care. There is now a compelling case to be made to accelerate adoption of these digital technologies into hospital settings – as part of a wider wireless ecosystem – to drive improvements in care. They will provide clinicians with continuous, real-time information and analysis that could enable them to make better decisions – and ultimately optimise patient outcomes at reduced cost.

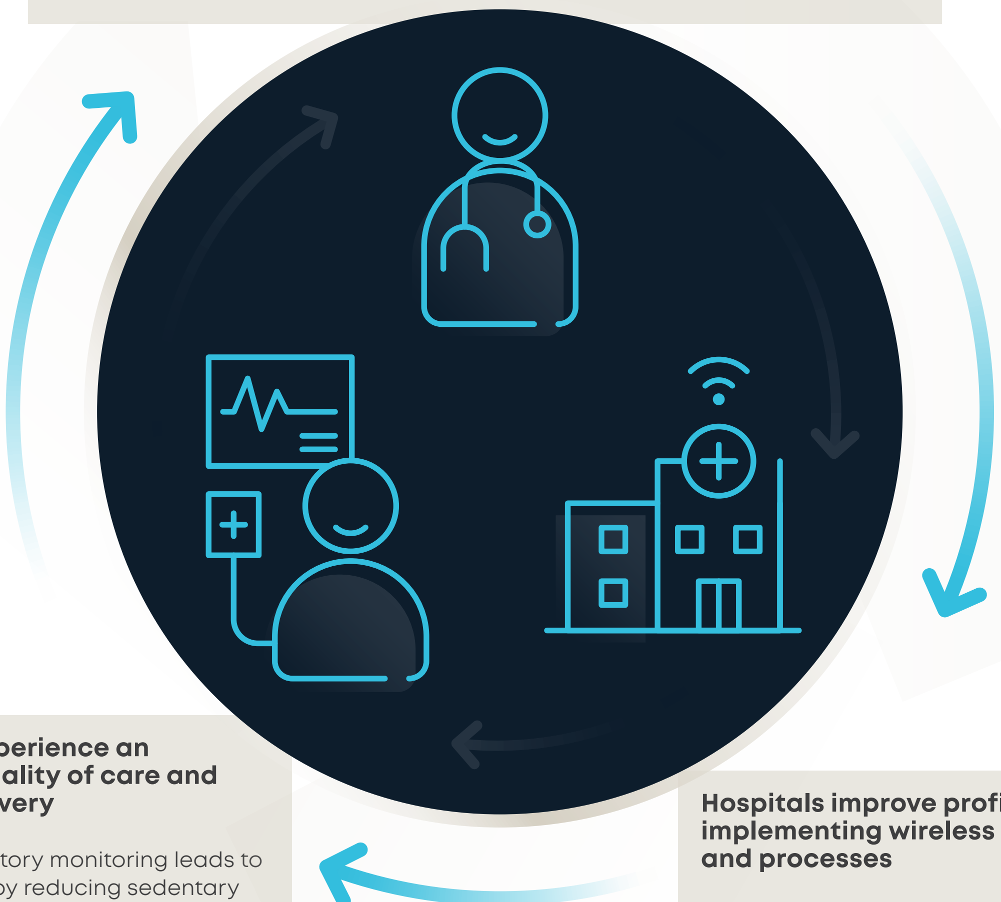
This whitepaper describes the benefits of introducing advanced wireless capabilities into surgical and critical care settings, the technical approaches to achieve this, and the challenges that can arise. It concludes with our vision for some exemplar use cases.

2 Why go wireless?

The benefits of adopting wireless connectivity in settings such as the intensive care units (ICU) and operating rooms (OR) are far-reaching. They bring improvements for all stakeholders in the healthcare ecosystem, from patients to clinicians to hospitals (see Figure 1). Removing the wires in medical systems can help to improve device ergonomics and increase patient mobility, enabling easier data collection, remote monitoring, and continuity of care. Combined with intelligent data analysis platforms, these benefits could be even greater and therefore represent a significant opportunity for medical technology companies to fulfil their customers' needs.

Physicians become more efficient in providing care for patients

Eliminating cumbersome wires in the OR improves a surgeon's manoeuvrability, leading to better outcomes. Doctors and nurses can remotely monitor and care for patients and leverage insight obtained using AI analytics to tend to the highest priority patients.



Physicians experience an increase in quality of care and speed of recovery

Wireless ambulatory monitoring leads to faster recovery by reducing sedentary behaviour, allows for efficient patient transfers ensuring there are no gaps in vital signs measurement, and extends the time window of care to before and after treatment.

Hospitals improve profitability by implementing wireless systems and processes

The mobility and flexibility experiences by patients and physicians leads to cost savings and/or increases in revenue for the hospital. This in turn enables greater investment in effective systems and staff.

Figure 1

2.1 Benefit to patients

In hospital, a patient's principal needs are quality of care and speed of recovery. The mobility, ubiquity, easy data collection, and continuity of care provided by wireless technology can help support these aims.

While in hospital, patients will spend on average 74% of their time sitting or lying down. However this sedentary behaviour has been shown to have profound detrimental effects on patients' health and ability to recover after treatment.[2] Wireless ambulatory monitoring systems allow vital signs to be measured while supporting early mobilisation that helps improve outcomes for patients and speed up recovery.

The improved mobility afforded by wireless devices helps expand the use of continuous monitoring into areas such as general wards that are currently poorly served as conventional monitoring is typically used only intermittently. This continuity of care has the potential to benefit the patient by identifying concerning trends more rapidly and reporting these to the relevant clincial staff on a mobile device. A vulnerable patient's condition can therefore be automatically and remotely monitored through the whole in-hospital pathway and even post-discharge.

2.2 Benefit to clinicians

While patients benefit first and foremost from wireless connectivity, physicians and nurses can also leverage the technology to meet their most fundamental needs: efficiency and ease of providing care in a high stress environment.

Wireless monitoring devices allow healthcare professionals to remotely evaluate a patient's condition and provide care without having to be physically at the bedside. For example, critical care outreach teams can see how a patient of concern on a general ward is progressing and whether intervention or admission to ICU is warranted.

An even greater benefit is achieved if such remote patient monitoring (and intelligent data analysis) is combined with information provided to clinicians by means of portable wireless devices, such as tablets. The data collected from patients can be stored, analysed and retrieved in real time by clinicians as they move through wards or into surgical settings. Remote monitoring and care would make health care providers more efficient as they make data-driven decisions, automate certain processes, and focus on the highest priority patients.

Aside from monitoring, wireless connectivity brings practical gains in other areas. In intensive care, where data may be aggregated from multiple devices around the bedside into the clinical information system, wireless connectivity can help reduce the sheer number of cables and complexity of the environment. It can also address issues such as limits on available networking ports. In the operating room, the removal of cumbersome wires can make it easier for surgeons to carry out certain procedures by increasing their range of motion.

2.3 Benefit to hospitals

As patient numbers increase, hospitals need systems and processes that reduce costs and are scalable. Enhanced data collection and continuity of care enabled by wireless has the potential to raise the level of quality of care, thereby lowering costs associated with hospital-acquired complications and readmissions that are not covered by reimbursement. Emergency readmissisons to hospitals within 30 days of discharge in the UK have sharply risen since 2014, costing the NHS £2.4bn annually.[3]

The ability to deliver more efficient provision of care can cut costs by reducing errors and increasing productivity and also boost revenue through increased utilisation of assets. Furthermore, more efficient systems make better places to work, helping attract and retain talented staff.

As part of the bundle of digital technologies, wireless connectivity therefore has the potential to improve the healthcare environment for all key stakeholders. The healthcare sector is already adopting wireless technologies for daily use in wards and this trend is expected to continue as the technologies advance and become commercially available. The digital transformation in the healthcare market is projected to grow from $147 bn in 2019 to $253 bn in 2023.[4] More specifically, the global market for portable medical devices was estimated at $44.2 bn in 2017 and is projected to grow at a compound annual growth rate of 8.7% until 2025.[5]

Of course, these benefits can only be realised with intelligently-designed devices, for patients and clinicians alike, that connect into a robust and reliable hospital-wide wireless ecosystem. In the next section we consider some of the wireless technologies that could enable that fully-connected hospital.

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3 Wireless technologies

Wi-Fi 5 is by far the most commonly used wireless technology in hospitals today.[6] However, as the system load increases, the wireless technology underpinning Wi-Fi 5 is incapable of delivering deterministic and dependable performance. While this lack of determinism can cause an inconvenience in other sectors (e.g. re-buffering for online video streaming), within a clinical setting, an unexpected performance degradation can often mean that the service is unusable. This problem will intensify with increasing connected device density and increasing performance requirements (typically higher throughput, lower latency and jitter) associated with each device.

The latest generation of wireless connectivity technology provides significant performance enhancements with respect to latency, network reliability, data throughput, security, and more, unlocking new wireless use cases in hospitals. The technologies at the cutting edge of wireless connectivity today are 5G and Wi-Fi 6. Table 1 below summarises each protocol's performance attributes and the section following it outlines their specific benefits to healthcare.

Protocol	Frequency	Range	Peak Data Rate	Latency
5G Public 5G eMBB: (Private 5G spans all three bands)	Low band: < 1GHz *Licensed spectrum*	"blanket coverage" (~10 km)	30-250 Mbit/s	Typically ~ 10ms. Lower latency possible with targeted optimisation (down from typically ~ 20 ms with 4G)
	Mid band: 1-6GHz *Typically licensed spectrum* *Unlicensed and shared spectrum also available*	"metro coverage" (~1-2km)	100-900 Mbit/s	
	High band: 24-40GHz *Typically licensed spectrum* *Unlicensed and shared spectrum also available*	"Line-of sight" (typically < 100m)	1-3 Gbit/s	
Wi-Fi 6 **(802.11ax)**	2.4 and 5GHz (also 6GHz for Wi-Fi 6E) Unlicensed spectrum	20-50 m	Up to 9608 Mbit/s (compared to a theoretical maximum of 3460 Mbit/s with Wi-Fi 5)	Typically ~ 20ms (only if uncongested) (75% less than Wi-Fi 5)

Table 1
*Refers to Standalone 5G that uses a 5G core network

3.1 5G and Private 5G

5G is the fifth generation of cellular network technology standards introduced in 2019. 5G targets three primary usage scenarios:

- Enhanced Mobile Broadband (eMBB) to deal with increased data rates, high user density and high traffic capacity for hotspot scenarios
- Massive Machine-type Communications (mMTC) for the IoT, requiring low power consumption and low data rates for a large number of connected devices
- Ultra-reliable Low Latency Communications (URLLC) to cater for safety-critical and mission critical applications

Achieving the performance associated with each of these usage scenarios requires different optimisations, which are often not mutually compatible. For example, the low power consumption associated with mMTC means that the data rates associated with eMBB use cases cannot concurrently be realised (at least not for the same device).

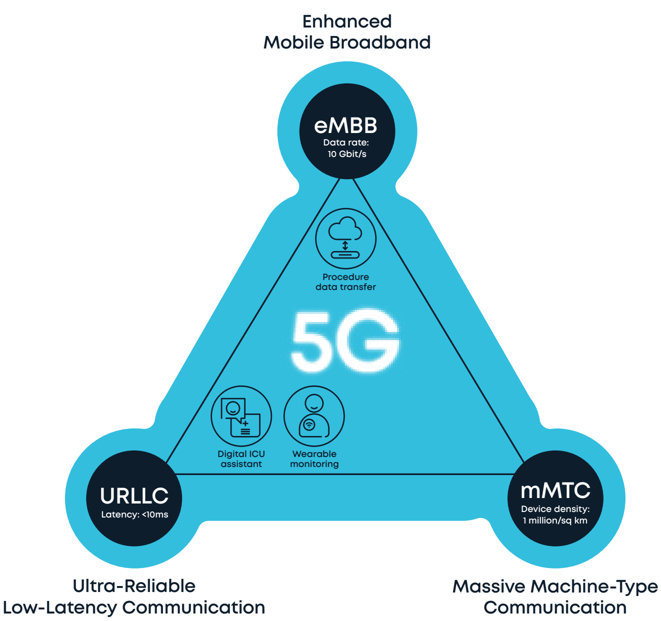

Figure 2

Public 5G networks, primarily targeting eMBB use cases, are being rolled out by mobile network operators (MNOs) in many regions today, but coverage is still sparse in many locations. While coverage will improve over time, many of the benefits associated with 5G can only be realised with millimetre wave spectrum, but this spectrum is known to have poor performance in non-line of sight conditions. This means that in-building applications (such as in a hospital setting) will not experience the full benefits associated with 5G unless an in-building solution is deployed to provide targeted coverage.

Furthermore, in an industry where MNOs draw most of their revenue from the provision of consumer mobile broadband services, it remains unclear to what extent and when they will venture out into mMTC and uRLLC use cases as part of their 5G offering. In response to this uncertainty, various communications regulators across the world have begun releasing chunks of spectrum that enable enterprises to create their own mobile private networks. Such networks offer healthcare providers a connected campus underpinned by an ultra-reliable, self-contained, and secure wireless network with numerous benefits over a public 5G network:

- Dedicated bandwidth without risk of congestion from competing services – essential to be able to guarantee a high level of reliability for mission critical applications
- Coverage in areas poorly served by public networks – ability to decide where 5G cells are located to optimise coverage, in particular hard to reach areas such as staircases and elevators
- Customisation – service levels defined by the hospital's unique requirements

5G is a complex technology that will enable many different types of use cases across various industry sectors. As a result, expert customisation of an enterprise's private 5G network to suit its specific needs and map its requirements to use cases is paramount. To accomplish this, important decisions have to be made on where in the 5G triangle to operate: does the hospital move towards the URLLC corner to enable mission-critical surgical intervention using wireless devices that operate at millisecond latency? Alternatively, does it move towards the mMTC corner to create an IoT hospital, a connected ecosystem containing 1 mn connected devices per square kilometre (equivalent to 20 devices in a 20 square meter / 220 square foot patient room)? Both of these decisions require compromising on the other performance metrics. Alternatively, the hospital can decide to partition the network (through a technique known as spectrum or network slicing) and use more than one client device to serve requirements operating in multiple corners of the triangle.

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Chicago's Rush University Medical Center is one of the early pioneers for 5G deployments specifically targeted to medical campuses. By partnering with AT&T to install a 5G network in one of its campus buildings,[7] the Center has avoided spending millions of dollars upgrading its existing cabled network infrastructure. Other examples of deployments, more directed to showcase the technology, include:

- A hospital in the Sichuan province in China that has built the 'world's first medical 5G network' in collaboration with China Mobile and Huawei [8]
- AT&T's roll-out of a mobile private network for the Lawrence J. Ellison Institute of Transformational Medicine in the US [9]
- Korea Telecom's deployment of a private 5G network at the Samsung Medical Centre in Seoul, Korea [10]

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3.2 Wi-Fi 6 (IEEE 802.11ax)

Wi-Fi 6 (based on the IEEE 802.11ax standard) is the latest WLAN technology released by the Wi-Fi Alliance. It operates in the same 2.4 and 5GHz frequency bands as its predecessor Wi-Fi 5, with an updated version of the protocol named Wi-Fi 6E that extends it to support additional spectrum in the 6GHz band, effectively reducing congestion and latency for devices operating in this band. It boasts numerous benefits over Wi-Fi 5 in the form of higher data rates with a theoretical throughput of 9600 Mbit/s, 75% lower latency, wider coverage, and better protection against interference.

As noted earlier, the wireless technology underpinning Wi-Fi 5 is not designed to deliver deterministic performance with increasing load. While Wi-Fi 6 does present higher data throughput capability, the performance improvements in loaded conditions are what primarily sets it apart from previous generations. In contrast to 5G, Wi-Fi 6 however still relies on unlicensed spectrum. This means that Wi-Fi 6 is still more susceptible to uncontrolled interference from other services sharing this spectrum.

The latest generation of wireless connectivity technologies will accelerate digital transformation in hospitals. However, this remains a complex landscape with a plethora of options available. Wi-Fi 6 will be better suited for non-critical applications due to its unlicensed spectrum and relative ease of deployment. Conversely, building a private 5G network requires more planning and specialist resources in return for additional flexibility and reliability required for mission-critical applications. However, selecting the right technology will be heavily dependent on the specific requirements of the hospital and the types of devices it is seeking to implement.

4 Challenges

Notwithstanding the potential benefits of wireless medical devices, eliminating wires is a complex process. The seemingly simple task of replacing an optical cable with a wireless radio frequency (RF) module is, in reality, difficult for multiple reasons. A number of hidden constraints emerge when designing a wireless system. Latency, reliability, throughput, security, and error rate are of lower concern in a wired system, as they are easier to guarantee. When designing an RF system, contribution of these potential failure modes needs to be carefully considered as part of the overall system risk assessment.

One of the biggest challenges in implementing wireless communications technologies in any environment is ensuring network reliability. Operating in free space leaves the potential for interference to affect the signal transmission, and in a healthcare environment in particular, such interference is unacceptable in mission critical applications. Fundamentally, there are two sources of poor reliability.

First, adjacent wireless devices that transmit and receive signals in the same or adjacent frequencies are prone to generate interference. For example, Bluetooth devices operate in the same band as some Wi-Fi devices. Even though they are not connected to the same access point (AP) and use a different protocol, these signals can interfere and negatively impact the end user's experience. Additionally, devices within electrosurgery units can generate substantial RF interference.

Second, additional latency can be caused by overloading a communications link. Wi-Fi protocols (5 and before) are designed such that the AP can only receive messages from one connected device at a time. If more than one connected device attempts to send packets of data at the same time, the router's collision avoidance system will hold back all but one, increasing latency.

Aside from the technical challenges, incorporating wireless communications into a medical device also comes with considerable regulatory implications. Device manufacturers must comply with standards that ensure electromagnetic compatibility, including thresholds for emitted signals in the various RF frequency bands. Furthermore, integrating a wireless module is far from straightforward; it is highly multidisciplinary and requires input from engineers in all areas of the RF stack: user experience (e.g. pairing), application demands, protocols, baseband electronics, antenna performance, caseworks, backend systems, cloud services and so on.

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5 Use cases

5.1 Wearable vital signs monitoring

Measurement of patient vital signs is widely used in hospital to help understand patient condition and guide care. In recent years, we have seen the emergence of wireless continuous vital signs monitoring devices in the form of patches or wearables.

Most commercially available medical wearable sensors communicate over wireless personal area networks (WPANs), a wireless network designed to connect electronic devices in a patient's personal space. The IEEE 802.15 is a collection of WPAN protocols including Bluetooth, Bluetooth Low Energy (BLE), ZigBee, and more. There is a specific subset of this collection of standards that is dedicated to real-time health monitoring and consumer electronics devices called wireless body area networks (WBANs) standardised by IEEE 802.15.6. Such protocols are characterised by low-power, short-range wireless communication, and are particularly common in wearable sensors due to the extended battery life provided by the module's low power consumption. While appropriate in certain settings, the use of WBAN protocols strongly limits the throughput and range at which the device can communicate with the hub, in turn severely restricting patient movement.

Currently many of these devices are approved for indications targeting the early identification of the deteriorating patient outside critical care. In these settings, continuous vital signs monitoring using wired devices can be impractical. Intermittent monitoring can lead to significant delay in detecting and responding to an arising medical crisis, leading to worse outcomes and higher costs of care.

In critical care, wireless monitoring would also have advantages. Cables can inadvertently be removed or damaged, causing additional alarms in an area already plagued by alarm signals. Cables are also constraining, which can be distressing for the patient, and they can limit free access to the bedspace, making a range of activities cumbersome, such as physiotherapy, turning the patient and intrahospital transport.

However, the transition to wireless connectivity for monitoring does not come without problems.

Robustness and reliability of connection will be key, particularly for critically ill patients where even a temporary loss of monitoring is highly undesirable. Wireless signals may be disrupted by patient anatomy or equipment around the bed. The signals may have a limited range, of relevance particularly where patients are ambulatory or are being transported. And wireless networks will have limited capacity. An increasing number of connected devices will put a greater burden on wireless capacity and slow down communication rates.

As for many IoT devices, another key area of consideration is power management. Recharging of devices is often not practical and reuse can be undesirable for infection control considerations. Many patch devices are therefore single use, where there are careful trade-offs to be considered between power usage for sensing, processing and communication and the use life of the device.

A notable benefit of using 5G for medical devices is its ability to offer hybrid coupling between cloud and edge computing. Rather than sending all health data to an off-premise cloud platform to perform all the analytics, data storage and computation capabilities can be selectively placed on-premise within the hospital, much closer to the device. The ultra-low latency offered by 5G would then allow patient data to be analysed in quasi-real time at different points in the network, providing valuable insight to healthcare professionals. Through careful optimisation, these short-range data transfers between the device and the network could be tuned to require less power, enabling the use of smaller batteries for sleek, ergonomic designs.

While previous generations of Wi-Fi have become ubiquitous in hospitals over the years, their use in small, low power devices has been limited. The performance improvements of Wi-Fi 6 now make the protocol a possible candidate for wireless monitoring devices.

5.2 Digital ICU assistant

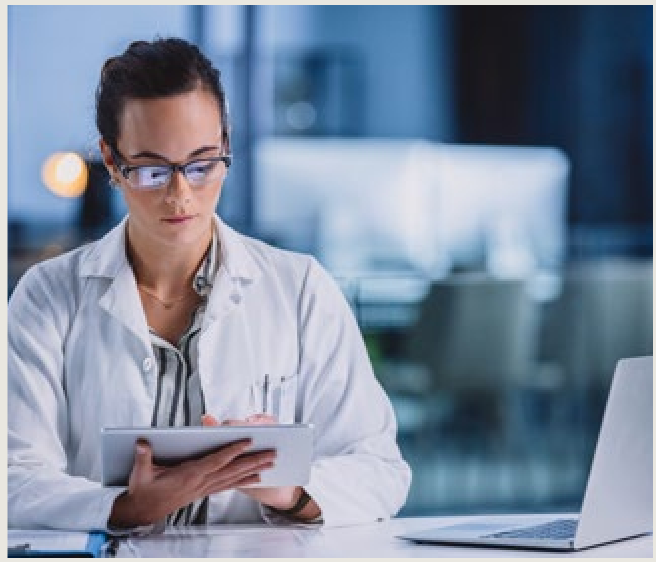
Hospitals have been a late adopter of mobile communications technology, with pagers still widely used in many developed markets.[11] The caution over the use of cellular devices has principally been due to poor reliability of signal, for example dead zones in lift shafts, stairwells and around imaging radiation protection shields, as well as the security of confidential patient data.

More reliable wireless connectivity, together with robust data security technologies, will accelerate the uptake of mobile devices. These will become much more than the simple alerting system that they are replacing, with the capacity to become powerful digital assistant platforms that can be used to provide timely reminders and insights to clinical staff as well as capture data.

In the short term, mobile devices can be used to help move interactions with information systems from fixed locations into the hands of staff, wherever they are. As well as alerts, this can include protocols, checklists and can be a portal to information from patient data through to practical device support.

Looking further ahead, mobile devices will host or access edge and cloud AI applications that can help augment staff capabilities and reduce cognitive burden. They may enable smart alarms, alert staff to deteriorating patients or priority tasks and provide insights to support clinical decisions.

Mobile devices can also help in better data capture of manual readings, observations and interventions. More complete data helps improve clinical decision making, whether or not that is supported by a decision support system. A key to capturing this data will be in making the interface seamless and easy to use, and new interface technologies such as voice recognition will be supported on mobile devices by reliable wireless access.



5.3 Procedure and equipment performance data transfer in the OR

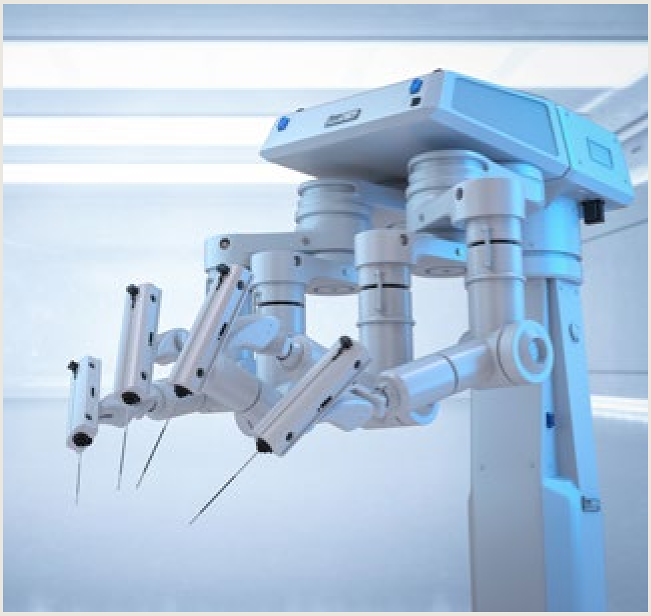
Hospital Operating and Procedure Rooms are primary data nexus points for the hospital. It is the culmination of millions of data points that leads to a decision to treat a particular patient in the manner set forth. But regardless of the complexity of the procedure being performed, operations also create billions more data points that capture what was done, how the patient performed during the operation, and how to treat them from here.

A wireless OR with the low latency of 5G or Wi-Fi 6 could enable an improvement in safety and efficiency, and thus patient care. Moving the computational components of large medical devices (i.e., imaging, diagnostic, and robotic systems) out of the physical environment of the OR could lower the footprint, weight, and cabling necessary to drive these systems. This could increase the access surgeons and nurses have to the patient while these devices are being used and provide a safer more open operating space for those supporting the procedure.

Smaller devices with increased computing power located away from the operating room could improve procedure workflows and maximise hospital return on investment, with one device being able to be easily moved from room to room without the necessity of adding a second or third system to keep up with demand. For the device manufacturer, the ability to capture real-time performance data enables proactive maintenance and support to minimise system downtime and allow for a more streamlined group of individuals to cover more service areas, thereby lowering operating expenses to support their devices.

As more technologies arrive on the market that provide in-situ analysis of tissue and abnormalities, wireless connectivity can improve the efficiency of diagnoses from hospital staff (i.e. pathology) without the constraints of location of the individual or speed with which samples can be transported between locations. As that data and the introduction of Digital Assistants and AI into procedure recording increase so too will the immediate sharing of how procedures were performed and how best to care for the patient moving forwards.

All of these advancements could increase the efficiency of the operative environment and lower the time and mental burden for the surgeons to share this data set. As the revenue centre for the institution and where everything is measured in cost per minute, any efficiency gained in the operating room can have large impacts for hospitals and health systems.



6 Conclusion

The emergence of the latest wireless connectivity technologies represents a significant opportunity to medical technology companies operating in the hospital space, including in surgical robotics, navigation and visualisation systems and critical care systems.

Wireless connectivity technologies have advanced to meet 5G and Wi-Fi 6 standards, bringing a range of potential performance benefits, such as low power modes, low latency, improved deterministic performance, and increased capacity and throughput. In combination with IoT and AI, these technologies will now support the emergence of wireless enabled ecosystems for smart assistance of hospital healthcare. In a myriad of use cases, systems and devices will collect and analyse patient data in real time to generate actionable, insightful information and deliver this to the right person at the right time. Making such systems wireless will support the mobility of patients and staff and flexibility of system architecture, particularly with respect to where computation happens.

By developing solutions for these use cases, medical device companies will deliver important benefits to key stakeholders. Clinicians can deliver care with more efficiency and greater ease, helping patients to recover faster and better with fewer complications, and helping hospitals to become more profitable by reducing their operating costs and increasing their revenue. And device companies themselves have the opportunity to seamlessly capture performance data to optimise operations and inform future product generations.

Advanced cellular technologies are already being deployed outside healthcare and we are now starting to see private 5G networks implemented in hospitals as a practical solution for connectivity today, giving a realistic time horizon for the opportunuities that the infrastructure will bring.

Medical device companies that are able to adopt, integrate, and exploit emerging wireless connectively technologies will gain significant competitive advantage. We believe that medical device companies should be exploring and understanding the opportunities that are being opened up by new wireless technologies. They should be working out which wireless technologies to incorporate into their roadmaps and how to access these. And they should be developing and testing system concepts to be in a positon to move into full development.

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About Cambridge Consultants

While the integration of wireless communications in medical devices presents multiple challenges, Cambridge Consultants is strongly placed to address them given our in-house expertise in all areas of an RF enabled stack and extensive experience of developing breakthrough medical devices. Our exceptional blend of technical depth, clinical insight and commercial expertise allows us to develop medical platforms that go beyond traditional boundaries. From implanted Class III devices to critical systems, we deliver solutions that excel in real-world clinical environments.

Cambridge Consultants has a proven record of strategic consultancy and technology development in wireless-based applications. Our technical expertise covers a range of disciplines, from high-performance radio systems and advanced antennas to service management platforms and machine learning. Our industry expertise spans utilities, warehousing and logistics, as well as healthcare and agriculture. We know and understand the requirements of each of these industries and we have experience in creating dedicated cellular and bespoke connectivity solutions which power many of the biggest corporations in the world. We can be your guide when it comes to vaulting the barriers and planning a path for the next five to ten years of success.

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