White Paper

Next Generation and Standards

The Need for Enabling Touchless Technologies

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1. The Digital Age

Digital technology has found its way to every corner of our planet. A significant portion of this unprecedented growth is owed to communication systems and especially wireless communications. This expansion has led to the emergence of thousands of different electronic devices – from PCs, printers and scanners to tablets, smartphones and smart watches – used by governments, businesses, and in our personal lives since the onset of the Digital Age just 50 years or so ago.

A large majority of these devices are controlled by buttons and, more recently, by touchscreens, many of which are multi-user public devices. These include ATM screens, vending machines, credit card readers, elevator panels, office equipment, kiosks at shopping malls, etc. The efficiency, comfort, and ease that touch-based digital devices have introduced in our lives is astonishing.

The economic impact of these devices likewise cannot be overestimated. They are our portal to the digital world, fostering an ever-increasing portion of the overall global economy. According to the World Economic Forum, more than 60% of global GDP will be digitized by 2022[1]. Indeed, it's hard for many of us to imagine how we would do business or even function on a daily basis without their help.

The proliferation of public touch-based devices has generally not been a cause for concern from a public health perspective. Our average living condition, health status, and life expectancy have all generally been improving while we increasingly rely on these devices and collectively enjoy the conveniences they afford. However, the rapid and expansive spread of COVID-19 brings with it a new reality, one in which we must minimize public health risks through developing and implementing technologies that minimize the likelihood of the spread of highly infectious diseases. This is particularly true for devices that function by touch or proximity.

For example, an average self-check-in screen at a busy airport can contain more than 250,000 CFUs[2], greater than 13 times the average of an airport water fountain button.[3] Viruses from one contaminated surface can be transferred to as many as six others by one hand, with some pathogens lasting up to nine days on a surface.[4] Given that people touch their faces more than 20 times an hour on average – including their eyes, nose and mouth – touch surfaces can be a leading pathway to the spread of cold and flu viruses, let alone a coronavirus like COVID-19.[5]

2. New Technologies Enabling a Health-Centric Way of Life

Our society can significantly benefit from technologies that minimize the need for touching public surfaces or help us operate devices at a safe distance. Bluetooth, Near-Field Communications (NFC) and other contactless technologies are mature and increasingly utilized, but they have been designed for purposes other than minimizing the need for touching public surfaces. As a result, these technologies require us to have active digital devices with us at all times, and need a two-way signal/data exchange between the user's device and the other devices (elevator, kiosk...), which may not be desired or fully reliable in all scenarios.

Through advances in radio technology and computing, millimeter wave radios and applications have been introduced to consumer electronics, including smartphones and laptops, and are now being integrated into a large variety of devices intended for everyday use. Millimeter wave signals could be used as a presence detector and accurately detect when a person approaches a certain object and/or location, as illustrated in Figure 1, in a way similar to how a radar works albeit with very low power and short range. For instance, radios described in this paper are allowed in the US to operate at 10 milliwatts, which depending on the operational parameters, could have a range in the order of a few centimeters (e.g. for detecting movement of fingers) to a few meters (e.g. for detecting presence in a room). Once presence is detected, appropriate automated events could be triggered and cause, for instance, an elevator to be called or warning lights in a pedestrian crossing to light up.

Figure 1. Millimeter wave radio as presence detector

2.1 Basic Principles

The primary advantage of millimeter wave radios over traditional ones that occupy frequencies below 30 GHz is *bandwidth*. The large amount of potential bandwidth available in the millimeter wave band is key to enabling important use cases. For communications applications, wider bandwidth translates to greater network capacity and higher data rates, making millimeter wave radios of great interest for both 5G cellular and Wi-Fi systems. For example, there is approximately 14 GHz available for unlicensed use in the 60 GHz band in countries including the US and within Europe.

Close proximity and movement detection using millimeter wave radios uses the same operational principles as radars. For radar applications, wider bandwidth leads to *increased resolution*. Specifically, for systems based on Doppler processing[6], the range resolution, R_r, (i.e. the ability to distinguish two different ranges on the same bearing) is given by

Equation 1.
$$R_r = \frac{C}{2 * B}$$

in which *C* is the speed of light and *B* is bandwidth.

The above equation results in a range resolution of approximately 2 cm for a system utilizing 7 GHz of bandwidth.

Also, the maximum unambiguous velocity, v_{max}, i.e. the maximum radial velocity that could be clearly detected, is equal to

Equation 2.
$$v_{max} = \frac{C * f_r}{4 * f_c}$$

in which *C* is the speed of light, and f_r and f_c are repetition frequency and carrier frequency, respectively. The above formula results in a maximum unambiguous velocity of approximately 2.5 m/s for a 60 GHz system with a repetition frequency of 2 kHz.

Both the carrier frequency and the bandwidth of signals transmitted by the system limit its resolution (range and velocity) and, consequently, the applications the system can support. Therefore, signal parameters are chosen in such a way that the application Key Performance Indicators (KPIs) can be met (as further discussed in Section 3 below), taking into account implementation constrains, such as a maximum power consumption limit. It is worth noting that radio and application requirements may lead to conflicting signal/system requirements; trade-offs are often a necessity when designing detection systems. Also, since different applications may have contrasting requirements, additional hardware may be needed to support multiple applications on the same platform.

2.2 Technology Development

There are technological challenges in the domain of radio design for millimeter wave motion detection and sensing applications that must be met in order to make them widely adopted toward creating a health-centric way of life. The technology used in the majority of current millimeter wave motion-detection implementations is FMCW (Frequency-Modulated Continuous-Wave); this technology is well-known and widely used but has limitations in dense deployment scenarios and/or when operating near other technologies that use the same frequency band.

As a result, other technologies are currently being developed to support motion-detection and related applications, including Wi-Fi in the millimeter waves. For instance, the IEEE 802.11 Working Group has started a new activity on *WLAN Sensing* to develop a new amendment to the standard to support radar-like applications ranging from home automation to gesture recognition using the 2.4/5/6 GHz bands and 60 GHz band. The *WLAN Sensing* standard will include a coexistence mechanism to better support dense environments, as well as facilitate both communications and detection/sensing functionalities on the same implementation in the silicon.

2.3 Applications

To enable more advanced gesture-detection features and/or to increase detection range, millimeter wave systems could be implemented with highly integrated antenna arrays in a small form factor like the one shown in Figure 2. With the use of antenna arrays, which could include from 4 up to 256 antennas with current millimeter wave technology, radios transmit and receive signals *directionally* through narrow beams, allowing these radios to "observe" an area from multiple angles/directions. With appropriate signal processing, millimeter wave systems could be used to not just detect presence, but to also determine the number of people present in a specified location without the need for identifying them (Figure 3). This ability could be used in applications as simple as eliminating turnstiles or more complex ones such as assuring that the number of people within a specified location allows for *social distancing* based on current public health recommendations.

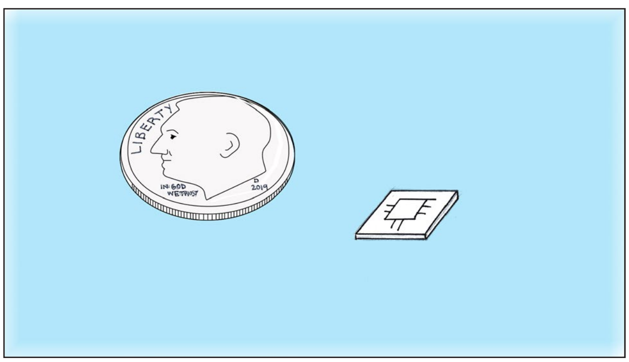

Figure 2. Millimeter wave antenna array

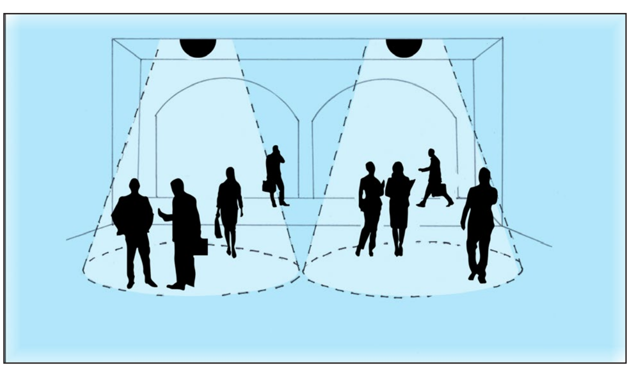

Figure 3. Counting people

2.3.1 Gesture recognition and remote operation

The *fine resolution* obtained with millimeter wave technology allows for the detection and classification of movement as small and subtle as that of the fingers in our hands. *Gesture recognition* relies on the same principles previously discussed for presence detection. Broadly speaking, once the object (e.g. hand) is within range of the millimeter wave system, its multiple features reflect and scatter back to the device a superposition of radio signals that intrinsically contain a *signature* of the motion (e.g. hand gesture) performed by the object over time. An example is illustrated in Figure 4 whereby the wireless keypad detects the number of fingers held.

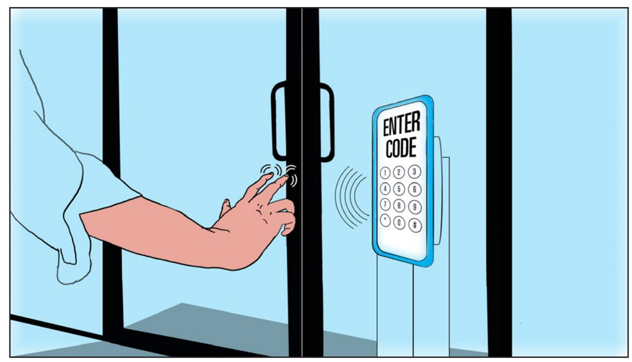

Figure 4. Motion detection and gesture recognition

After radio-signal processing, features known to allow for gesture classification, e.g. finger movements, are extracted from the resultant signal and passed on to an Artificial Intelligence (AI) algorithm for inference. Specifically, the AI algorithm classifies hand gestures against a predefined set of motions, such as lateral movement of the thumb to represent sliding or page-turning, up and down movement of the hand to represent swiping or scrolling, etc. While the computational complexity of AI algorithms for gesture recognition could potentially be high, it has been shown that processors currently used in smartphones, and even smaller devices such as smart watches, can suitably support them. More powerful processors or AI-specific hardware may be needed to enable more advanced applications, including those that involve the recognition of fine movement of multiple objects simultaneously.

As a result, current millimeter wave radio and computing technology provides us with the ability to replace touch-based interactions with touchless ones through the recognition of hand gestures performed in the air. Such ability is particularly valuable in situations where touch-based interaction is not possible or desired. As shown in Figure 5, the technology could be used to replace conventional touch screens – and remove the current health risks associated with using them – and facilitate communication with a device by interacting with it from a safe distance.

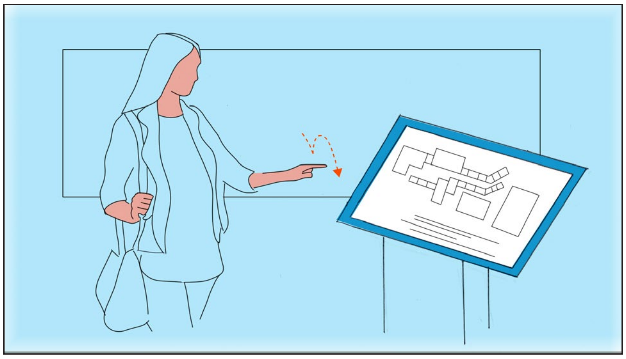

Figure 5. Example of the use of gesture recognition

Millimeter wave presence and gesture technologies by their nature are also anonymous. No personal data is needed to recognize how many people may be in a room or if one of them waves his or her hand over a touchless display. Consider the airport setting. Using hand gestures and finger movements to navigate through an airport at a distance, from an elevator to a touch(less) screen ticket machine and the check-in counter, would not only minimize the risk of spread of infectious diseases but also reduce environmental impacts by lowering the need for disposable material.

2.3.2 Applications in health

Over the last couple of decades, research conducted by various academic and industry projects have time and again demonstrated the ability of millimeter wave sensing to perform *contactless vital-sign monitoring* through the estimation of breathing rate and heart rate. The principle behind this application is that millimeter wave technology can detect and track vibrations containing cardiopulmonary activity in a person's torso, as illustrated in Figure 6.

Figure 6 Contactless breathing and heart-rate monitoring

Providing high levels of reliability and accuracy is essential for some health applications, such as contactless vital sign monitoring; measurements must not be noticeably impacted by, for example, slight movements of the subject. To "denoise" the measurements – that is, eliminate or mitigate the impact of measurement errors – it is often possible to make use of side information provided by other technologies and/or sensors that exist in the same system as the millimeter wave detection system. Most laptop computers, as illustrated in Figure 7, are shipped with several sensors, such as an accelerometer, ambient light sensors, and gyroscope, along with a Wi-Fi radio. It is possible in principle to gather information from all these elements and identify environmental variables that could impact measurement processes.

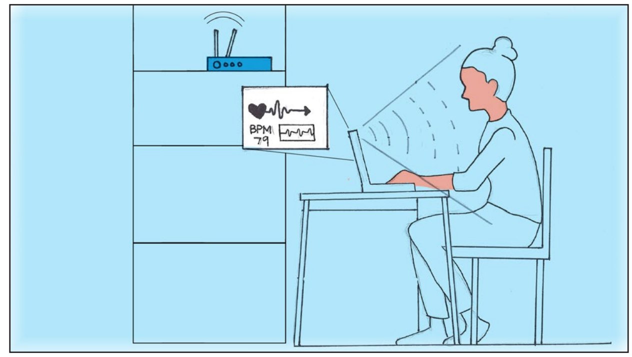

Figure 7. Using laptops for health analytics and remote health monitoring

Modern platforms that include computing and radio capabilities, (e.g. laptops and smartphones) are expected to be commonly used in the future as a hub to collect and analyze health information – at a significantly larger scale than current fitness trackers. For example, for computer users who spend a significant number of hours in front of a laptop, the information gathered on an opt-in basis can be extremely valuable in the detection and prevention of potential health issues, the same way a fitness tracker is used but on a larger scale. More than just a teleconferencing tool to speak with your physician, as many of us are doing these days due to social-distancing requirements, upon consent, your laptop could also be able to provide your physician with relevant data, both historical and in real time.

3. Essential Characteristics

Key performance indicators (KPIs) used to characterize and benchmark wireless systems and devices when used for detection and sensing are, by nature, different from the ones traditionally used for communications, such as transmission rate and symbol/packet error rate. In addition to the metrics we've previously discussed (range resolution and the maximum unambiguous velocity), detection and sensing applications may also impose *radio-level requirements* on maximum range, angular resolution, and angular field-of-view, among others. Specific values for these parameters may vary greatly, depending on factors such as the target application and implementation, form factor of the device, and the setting/context in which the device is deployed.

In addition to radio-level metrics, KPIs are also defined for applications involving sensing. For a gesture recognition system, the important KPIs are the reliability and accuracy in which the system "spots" the hand of the user in different backgrounds – which could vary from a plain wall to an outdoor environment with multiple people moving – and the reliability and accuracy in which the system then classifies the gesture into a pre-defined set of gestures.

For example, in presence-detection applications, the sensing range typically varies from 1 to 10 m, the field of view could be as narrow as 30° or as wide as 360° for different usage models, and the detection accuracy is often required to be no less than 90-95%. For gesture recognition, while the sensing range is normally smaller, from 50 cm to 1 m, the field of view is also narrower, approximately 150° or less, while the detection/classification accuracy usually remains the same at no less than 90-95%.

Dependency of the range resolution on required signal bandwidth, based on Equation 1, is depicted in Figure 8, while unambiguous velocity as a function of carrier frequency, based on Equation 2, is shown in Figure 9 for three different repetition frequencies.

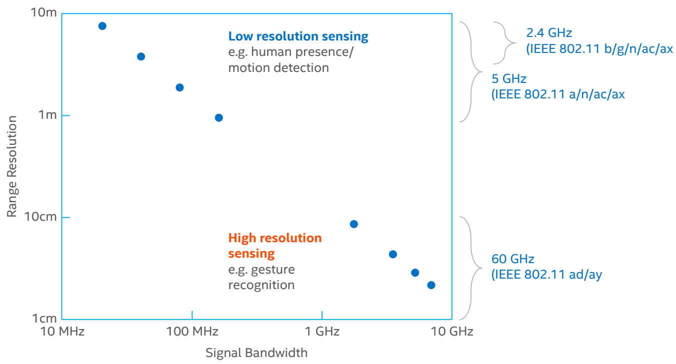

Figure 8. Relationship between range resolution and signal bandwidth

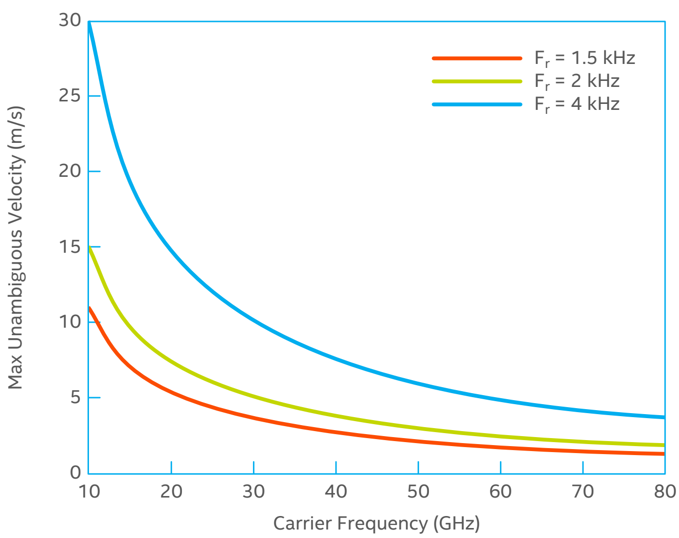

Figure 9. Unambiguous velocity as a function of carrier frequency for three different repetition frequencies

Latency and refresh rate typically range from 10 ms to 100 ms and from 100 ms to 1 s for gesture recognition and presence-detection applications, respectively.

The computational complexity of a sensing solution is another important KPI and, as mentioned, recent advances in computing and AI/ML[7] hardware have been key in enabling its implementation in relatively small form factors.

4. Conclusion

While digital devices have become essential to our daily lives, we find ourselves in a new reality that requires us all to rethink how we engage with the world around us. Touchless presence and gesture-based technologies in public settings, particularly those enabled by millimeter wave technology, could be instrumental in helping us reduce the need to touch surfaces in public settings.

The unique characteristics of the millimeter wave spectrum, including its potentially large amount of available bandwidth, allow it to reliably address contactless use cases as described in this paper. The emerging WLAN Sensing standards and highly integrated antenna arrays can help optimize millimeter wave performance in dense environments, while AI computing and hardware advances allow even small mobile devices to support the required computational complexity inherent in sensor solutions.

With today's technology and advances on the near horizon, digital devices have the potential to take yet another meaningful step forward in aiding our daily lives. With the help of millimeter wave technology, digital devices in public settings can be transformed to become vital tools to help promote public and personal health.

[1] https://business-reporter.foleon.com/business-reporter-2019/digital-economy-and-transformation/the-impact-of-the-digital-economy-on-business-strategies/\
[2] Colony-Forming Units of bacteria or fungus
[3] "Germs at the Airport," Insurance Quotes, January 2018, https://www.insurancequotes.com/health/germs-at-the-airport
[4] Lei, H., Li, Y., Xiao, S. et al., "Logistic growth of a surface contamination network and its role in disease spread." *Sci Rep 7,* 14826 (2017). https://doi.org/10.1038/s41598-017-13840-z
[5] Shafaq Zia, "How touching your face can spread viruses — and why you're so bad at avoiding it." https://www.statnews.com/2020/03/09/how-touching-your-face-can-spread-viruses-and-why-youre-so-bad-at-avoiding-it/, March 2020
[6] Doppler radars estimate the range and velocity of targets by bouncing radio signals off them and processing changes to the timing and carrier frequency of returning signals
[7] Artificial Intelligence/Machine Learning