"Sound of silence": a secure indoor wireless ultrasonic communication system

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> "You do not really understand something unless you can explain it to your grandmother." (Albert Einstein)

Ubiquitous wireless technology

According to a report from the World Health Organization, over 1.4 million mobile phone base stations exist worldwide today, and that number is significantly increasing with the emergence of new communication technologies. What about mobile phones? The International Telecommunication Union (ITU) claims that there are almost as many mobile phone subscriptions in the world as people. And that's about 6 billion! The growth of wireless networks has enabled people to use personal devices anywhere at any time. Wireless communication nowadays has become a utility like water, electricity and gas. With the convenience and efficiency it brings, we also have to consider some issues with this technology, because it is so fundamental to our everyday lives.

Problems

One critical and urgent issue is wireless availability. Like the laptops, mobile phones and tablets we know and love today, wireless devices communicate with each other using what are known as radio waves. Useful radio waves are limited, expensive and strictly regulated. What is worse, we are simply running out of suitable frequencies to use. There is another issue you may already be aware of. We are told to switch off our mobile phones during flights because our devices may potentially interfere with on-board electrical systems. The same thing happens at home as well. You will sometimes hear a strange noise coming out of your PC speakers or headphones when your mobile phone is ringing or when you are sending text messages. Also, some studies have shown that wireless radio devices might interfere with implanted cardiac pacemakers if used close to them. These are all radio interference issues. The unwanted wireless signals will significantly degrade desired signals and reduce system performance. Additionally, wireless networks have many security threats. Because radio signals can pass through solid obstacles very easily, they can be intercepted. For example, somebody outside your room can intercept your wireless Internet connection and steal your personal information (bank records, passwords) without difficulty.

Solution

Fortunately, we have sound! Sound is a mechanical vibration or pressure wave that can be transmitted through a medium such as air, water or solid materials. Human beings and animals communicate with each other by making different tones of sound. But if data signals were transmitted using audible sound the environment would be too noisy for us. Therefore, the use of ultrasound becomes attractive. Ultrasound is simply sound with a pitch or frequency greater than the upper limit of human hearing (about 20 kHz). You will not be able to hear it without the help of a proper detector. The first technological application of ultrasound dates back to 1917 when Paul Langevin was trying to detect submarines using SONAR. Ultrasound nowadays is popular for medical imaging, industrial inspection, cleaning and underwater communication. Unlike radio waves, sound waves are regulation free and they cannot interfere with current wireless devices operating at radio frequencies. There are also no known adverse medical effects of low-energy ultrasound exposure. On the other hand, ultrasound can be confined easily due to the way that it moves. Ultrasound travelling through air does not penetrate through walls or windows. So if you have sensitive data transmitted using ultrasonic waves in air, nobody can intercept indoor ultrasonic signals from the outside. Current ultrasonic technology is not a competitor to radio based wireless communication technology. It does not have the same flexibility and coverage range as a radio system has. But they can be two parallel technologies working together side by side to make more secure and reliable wireless networks.

How does an ultrasonic communication system work?

One common way to send digital data using ultrasound is simply turning on and off the transmitter. It works like a switch, using the presence of an ultrasonic wave to represent a digit ‘1’ and its absence to represent a digit ‘0’. Therefore, digital data can be represented by a series of ultrasound bursts travelling as pressure waves through the air. When the receiving sensor detects the corresponding changes of sound pressure, this information can be converted back into an electrical signal and translated back to the original data.

Unfortunately, ultrasound signals can be very delicate. They can be affected by air flow, temperature changes, humidity or environmental noise. Changing temperature as well as humidity can cause ultrasound signals to fade away, thus limiting transmission to short distances of a few metres. Persistent background noise may degrade the system performance. Hence, we need to design a smarter scheme to deliver ultrasonic Wi-Fi. My work has focused on making the most efficient sound transmission scheme against the difficulties of the acoustic environment.

Figure 1: Tap water flow and shower streams. Image: Wentao Jiang.

As can be seen in Figure 1, water flowing out of a tap is in one big stream, while the same amount of water coming from a shower head gives many tiny little streams in parallel. You can block the tap water easily just with your thumb, but can you do the same thing to a shower flow? The answer is obvious. If the water flow from the tap is blocked by interference, the whole system will suffer from it. But is there a way to make data transfer like the multi-stream water flow from the shower head?

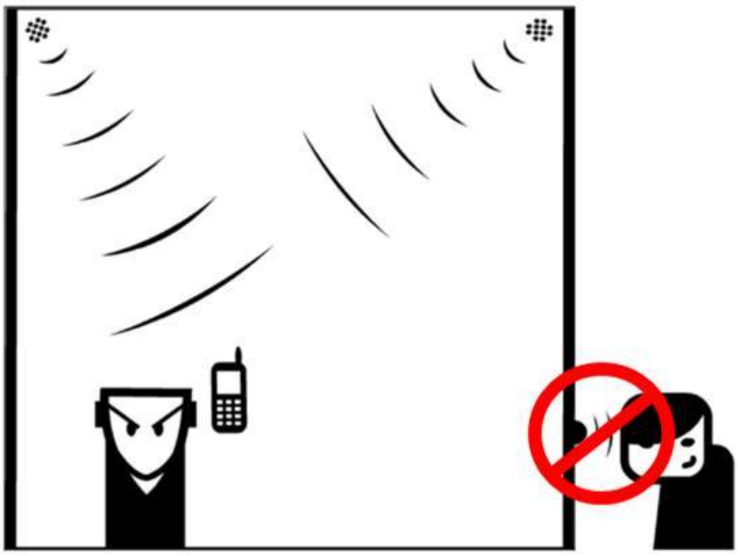

Figure 2: Secure indoor wireless ultrasonic communication. Image: Wentao Jiang.

If you go to a concert, you might have noticed that the music actually consists of different parts in terms of different pitches or frequencies. Lower frequencies may come from drums, cellos or basses while higher frequencies can be produced by trumpets, violins or horns. Vocals mainly cover the medium range frequency. Yet, you can separately hear individual instruments and voices mixed together in the same performance! Correspondingly, data signals can be divided and moved into different frequency channels. They can be added together afterwards just like a band playing music.

I have already successfully built a system that can transmit data using ultrasonic waves in air over distances of up to 5 m without error using multiple parallel data streams and the individual frequency channels separated and decoded. The next step is to build a two-way communication link. Like Wi-Fi and mobile phone networks, modern communications are mostly point-to-point systems that allow two devices to communicate with one another in both directions, simultaneously. The same idea can then be applied to an ultrasonic system. Lower frequencies can be used when transmitting the signal while higher frequencies can be used for receiving the signal. An intuitive way to understand the scheme is to place yourself in a building which is on fire. When the fire alarm has been activated, you can still talk to people who are close to you (low frequency sound) under the beeping sound (high frequency sound) from the alarm. Once the ultrasonic communication system (Figure 2) has been built, the location of your mobile wireless device can be determined by the length of time that elapses between the ultrasonic sensors installed on the ceiling sending the sound signal and hearing the returning signal. Since sound waves travel much slower than radio waves, the elapsed time will be much longer and the distance can be more accurately calculated. When the mobile device has been located, the ultrasonic sensors will be electronically turned and pointed to it, making the sound transmission more focused and more energy efficient. This also localises the signal so that other devices nearby cannot intercept it, even if they are in the same room. The ultrasonic system has been designed for indoor application and interception from the outside will be impossible.

Ultrasecure indoor wireless technology

Like many renewable energy technologies developed today, in the wireless communication realm, ultrasound can be a viable alternative to scarce radio waves as a way of transmitting data signals in certain situations. Ultrasonic communication schemes can also offer a number of advantages in terms of low cost, high energy efficiency and most importantly system security in an indoor environment. In intrinsically safe places like petrochemical plants where radio equipment is usually prohibited as it may generate antenna sparks, ultrasonic technology could be an ideal solution. It could also be used in a surgical operating theatre, where no sensitive electrical medical instruments would be compromised by radio wave interference. In aircraft cabins, it could be used as a Wi-Fi hot spot. People could log on to social websites or send emails during flight without worrying about any interference with any on-board electronics. Ultrasonic technology could be more commonly used at home and offices, and could make life much more secure. In the future, will we use the "sound of silence" to communicate?

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