Can the Radio Spectrum Ever "Fill Up"?
https://mindmatters.ai/podcast/ep253

Robert J. Marks:

Greetings and welcome to Mind Matters News. I'm your 5G host, Robert J. Marks. Chances are that right now you have all sorts of electromagnetic signals bouncing off of you and going through you. Think about it. When you turn on your cell phone, the cell phone is using a portion of the radio spectrum. If you have a radio, you can tune to many stations, all of which use a different part of the spectrum. Whether or not you have a radio, these radio waves are present where you sit, so are all of the broadcast television signals. Visible light is part of the electromagnetic spectrum, so unless you're sitting in the dark, wherever you are, you are in the presence of hundreds if not thousands of sources of electromagnetic radiation.

So, here's a problem. There are too many signals and useful spectrum bands that are filling up. The radio spectrum is filling up with users, especially in the so-called sweet spots, in the places where the electromagnetic spectrum has special properties. So, what should we do? Today, our guests are the perfect people to address this. Our guests include Google engineer Dr. Andrew Clegg. Joining Andy and me is Dr. Austin Egbert, who is a research scientist at Baylor University. Andy, how do we deal with the spectrum filling up? There has to be some sort of traffic cop somewhere or something. What do we do?

Andrew Clegg:

Yeah, well, so there's basically two ways to deal with the spectrum filling up, two obvious ways. One is to increase the efficiency with which the spectrum is used. So, in other words, if you want to transmit a certain amount of data, make your signal as efficient as possible so you can transmit as much data as possible while using the fewest number of frequencies. We call the range of frequencies you use the bandwidth of a signal. That explains the size of the chunk of the radio spectrum you have to use. So, the more data you can transmit to a user on a given chunk of spectrum, then the more efficient your transmission is and you can fit more users into the available amount of spectrum. So, that's increasing efficiency. That's one way of dealing with the spectrum crunch.

Robert J. Marks:

If I could interrupt?

Andrew Clegg:

Sure.

Robert J. Marks:

Using the spectrum efficiently has been something which I think is kind of a well-plowed field. Are we still making advances in this area?

Andrew Clegg:

Yeah, so that's exactly what, I was going to make that point in a minute, is that we have done a pretty good job getting close to in some ways theoretical spectrum efficiency in terms of Shannon's law and things like this, but there are still ways to make spectrum use more efficient that isn't purely in terms of the number of bits you can do per frequency. One of the ways that we're becoming more efficient is that we're using much more advanced antennas that are able to beam the signal only in the direction where it's desired and not send radio signals in other directions. So, if you have 10 users on a cell site, we're deploying antennas where the signals can be beamed directly at those 10 users and not send a lot of signals off in other directions. So, that's another way to improve efficiency, and that we're still developing technologies for, what we call beam forming and forming the radio beams that you send to different people. That field's still developing and it's getting quite sophisticated, but that's another way of effectively increasing the efficiency.

Robert J. Marks:

Let me ask you this about the cell phone.

Andrew Clegg:

Sure.

Robert J. Marks:

When you're talking and your cell phone broadcasts, is it omnidirectional? Does it go out with the same power in all directions, or is there beam forming that kind of points towards the cell tower, because if you pointed towards the cell tower, you could do more? I think it's the former, isn't it?

Andrew Clegg:

Well, it depends on the model of phone you have, but typically the more modern phones do in fact have some limited level of beam forming in them, not nearly as much as the base stations, because the beam forming requires giant antennas that are many wavelengths in size and multiple antennas that are spaced far apart. In the phone, there are typically multiple antennas, but typically it's going to be two or four, maybe not the number that you can put at a base station. There's very rudimentary beam forming implemented at the phone, so your signal tends to spread a lot more widely from a phone than it does from a base station, but the amount of power being transmitted by your phone is much less than the amount of power being transmitted by a base station. So, if you implement good beam forming at a base station, you are being more effective at limiting how much radiation goes in different directions because the base station is sending so much more power than the cell phone itself. But yes, the cell phone signal tends to be spread out more than the base station signal.

Robert J. Marks:

It seems to me that if you did have, you were able to aim your cell phone signal, that you would be using more energy towards the cell tower and wasting a lot less energy, and I think your battery would last a lot longer, wouldn't it?

Andrew Clegg:

Yes, and that's a good thought, and they have implemented some sort of basic features like that, but the reality is when you're talking on a phone, you're typically moving. You might be walking down the street, you might be in a car, you also move your head around, and even when you're talking, your jaw is moving, your hand is changing orientation. All sorts of things are going on that's causing that phone to move or causing the electromagnetic environment immediately surrounding that phone to change. And so having a good stable beam-forming solution gets much more difficult on the handset side.

On the base station, the antennas are absolutely stationary. You can also have a lot more computing power at the base station to do all the calculations to do the beam forming. And so in practice, it's a lot easier to implement beam forming on a base station than a handset. So, yes, you're right, it would be ideal if you could have just a very narrow beam coming from your phone back to the base station, but in practice, the amount of size and power and things that you would need to implement that and you'd have to stay very still to make it stable, it just isn't practical to have very high beam-forming efficiency from a handset.

Robert J. Marks:

Okay, that makes a lot of sense. Let me ask you another question. This is spectrum sharing in a way. When you're on the airplane, the flight attendants come on and say you got to turn off your cell phones. Why? What is that going to interfere with?

Andrew Clegg:

So, it's interesting. It's not an FAA regulation that is basically telling them to tell you to turn off your handsets on the plane. It really is an FCC rule, and there's a variety of reasons for it. The basic reason from one of the FCC rules is that it's possible that a cell phone transmitting up in the air can interfere with many base stations at one time. So, one of the ways that a cell phone network is designed is that a base station may use the same frequency as a neighboring base station uses in the same company's network, or they may have a grid of frequencies that are very carefully mapped out between cell sites to reduce the chance of cell sites interfering with themselves. And the assumption there is that the mobile devices are typically going to be where they're expected to be, and that is on the ground or in a building or something generally close to the ground.

When the cell phones get up in the air, in the air you can see for a very, very long way, which means your radio signal can also go for a very, very long way. And the concern was that you could cause disruptive interference to cell phone networks from a single cell phone on a plane that's interfering or a signal being received by multiple cell sites at the same time. So, that's one reason. The other reason is that there are sensitive avionics on a plane like aviation radars that measure the distance between the plane and the ground, or air traffic control frequencies or weather radar that's built into the nose of the plane. There's a number of systems on the plane that use radio waves, and there's always a potential that if you're using a cell phone transmitter inside the plane that it could interfere with some of the plane's avionics. But the reality is the avionics are generally well made. Traditionally, the frequency separation between where cell phones operate and where the plane's radars and things operate was significant.

I don't believe there have been any documented airline incidents caused by actual interference from a cell phone to avionics, so I think the concern is a bit overblown, but still probably not a bad idea not to have your cell phone on on the plane. But of course, these days now that you can get Wi-Fi on most planes, they're basically inviting you to turn one of the transmitters back on on your phone, which is the Wi-Fi transmitter. And in fact, some planes, not so much in the US but sometimes in Europe and other countries, they actually can have little cell phone base stations on their planes, and so you can use your cell phone in cell phone mode. So, obviously the fact that this wireless infrastructure exists on planes must mean that the chance of interruption to the avionics caused by your cell phone is relatively low, but for safety's sake, it's always a good idea if they ask you to turn your cell phone on to airplane mode and just keep the Wi-Fi on or whatever, it's probably a good thing to do.

Austin Egbert:

Yeah, it can also help with your battery life if it's not having to constantly search for a cell signal that it can't find many tens of thousands of feet in the air.

Robert J. Marks:

Another concern that I have heard about is that the altimeters for airplanes can be disrupted not necessarily by signals within the plane, but signals external to the plane. In other words, signals in the vicinity of the airport. Can either one of you elaborate on that? Tell me whether what I've heard is wrong or right?

Austin Egbert:

Yeah, basically what was going on there was with some of the rollout to 5G cellular networks, is that one of the bands that was allowed for use was next door to a band that has been used for aircraft radio altimeters. Basically these are sensors where the plane's able to send a signal down towards the ground as it's coming in for a landing or a departure, and then it listens for the reflection of that coming back up from the ground, and based on time of flight and whatnot, it can get an idea of how far away it is from the ground below it. In theory, there shouldn't be any issue, because it's using one frequency and the 5G systems are using a different frequency. If I remember correctly, a slightly lower frequency. The problem is that most devices, it's very difficult to create something that only transmits in this one particular set of frequencies and nowhere else.

You end up with what's called a spreading of your signal, where the electronics, you end up with sort of a roll-off. Most of your energy is in the band you wanted it in, but you still kind of leak a little energy transmitted on adjacent frequencies. And the concern was that some of this leaking energy would get close enough to some of the aircraft altimeters such that it could cause interference with the systems on those planes. And specifically, they weren't even necessarily worried about even the leakage being too close, but rather that some of the older systems on the planes would have filters that were too wide, and so newer systems didn't necessarily have this issue on the planes, because it would have a narrower filter.

Robert J. Marks:

Okay, a filter. Explain what a filter is.

Austin Egbert:

Essentially, a filter works where you're able to turn down the amplitude of certain frequencies, so the filter will be designed where it only allows signals of certain frequencies to pass through it.

Robert J. Marks:

Well, in fact, that's what you do with your AM or FM radio station, is you tune it so that only the frequency of that station gets through.

Austin Egbert:

Yes, exactly. Yeah, you can tune the filter, the band that the filter is designed to let through into the radio receiver, and that's how you can choose which signal you want to listen to. So, these aircraft altimeters would have a filter that was designed where it would only be able to pick up the signal that it was sending down and then the reflection of that coming back up.

Robert J. Marks:

So, a filter that was too wide would be for example on your FM radio station, your filter would be too wide and you would actually be hearing two or three radio broadcasts at the same time instead of one. That would be an example of a filter that had too big of a bandwidth?

Austin Egbert:

Yes. Yeah, yeah. Essentially, the older filters were with older technology, they didn't have as sharp of a cutoff. So, if you think of I want to only listen to frequencies from A to B, ideally I would have a sharp cutoff and I wouldn't hear anything outside of that range. But in practice, you get some sort of roll-off where you hear some frequencies below A and some frequencies above B. The sharper you can make that cutoff the more of an ideal filtering you get. Some of these older systems, the slopes were shallow enough, they weren't sharp enough of a cutoff, that there were concerns that some of the signals coming from those adjacent 5G systems would be able to leak through and still make it to the receiver of the aircraft systems and potentially cause issues.

Robert J. Marks:

So, in your opinion, should we be concerned about the overflow of frequencies that are in the same frequency area as altimeters? Should we be careful about keeping those out of airports?

Austin Egbert:

I think in this case, the solution is pretty well identified. It's just a matter of going in and updating those aircraft systems to have newer, sharper filters. It's kind of understandable why things progressed the way that they did. Typically in aviation, there's a very well-motivated mindset of if it's not broke, don't fix it. And so if the existing filters were working fine, there was not a need to replace anything, and you're potentially introducing additional risk by updating a system that you don't need to when the old system is working fine and has worked fine for decades. But in a situation like this where, okay, now we've brought these new systems in, now there's a motivating reason to go ahead and modernize some of those systems and implement sharper cutoffs that should improve the quality and performance of those systems. But because it was something new, it just didn't have the same reliability track record as something that had been around for forever.

Robert J. Marks:

Gotcha. Interesting. Let me ask you about another case where maybe we got to watch out for electromagnetic pollution, and these are radiometers. What is a radiometer? And I believe that they're used to help forecast the weather, right?

Andrew Clegg:

A radiometer is a device that measures basically natural radio emissions coming off of objects such as the Earth, either the land or the ocean, or even the atmosphere. We don't realize it, you don't often think about this, but anything that has a temperature above absolute zero radiates energy at all frequencies, and I do mean anything. You, me, the walls in your room, the computer you're sitting in front of, your phone, anything, even if it's not transmitting wireless signals, anything, just by virtue of having a temperature emits electromagnetic waves at all frequencies.

Robert J. Marks:

Wow.

Andrew Clegg:

Yes, which is very interesting. The thing is, the amount of radio waves, the strength of the radio waves they generate is very, very low. We typically call this, if something's radiating just because it's got a temperature, we call that thermal emission, and the thermal emission coming off of typical things like your body or your dog or whatever is very, very low. You typically wouldn't be able to pick it up with your AM radio in your house and things like that. But there are certain systems that are designed to listen specifically for this very, very weak electromagnetic radiation coming off of natural objects.

There's two types of systems that are designed to do this. One is a radiometer, which is typically used in monitoring the Earth. So, they're often on satellites looking down at the Earth and they're measuring, for example, the temperature of the land, or they're measuring the salinity of the oceans, or they're measuring the amount of attenuation caused by the atmosphere so they can try to measure the water vapor content in the atmosphere or perhaps even measure the water vapor content as a function of height in the atmosphere. They do all sorts of things by these radiometers. They're measuring just the thermal emission coming off of the water, the land, the atmosphere or whatever, and these data are fed into weather forecasting models.

So, you think about trying to monitor what the sea surface temperature is. So, if you're trying to figure out whether you've got the kind of heat in the water that can cause evaporation and create hurricane-type conditions and things as the water evaporates and convection currents start happening in the atmosphere, some of these measurements they make with radiometers on the satellites looking at the oceans from above can tell you that. And then also mapping out the water vapor content in the atmosphere can tell you how likely it is that it's going to rain or thunderstorms develop or whatever. And so these are passive instruments in the satellites that listen for this very, very weak but pervasive thermal emission coming off of objects in space.

The other type of system that listens to natural radio waves are radio telescopes. They're typically on the surface of the Earth and they're pointed out at the cosmos. Things in the cosmos, other galaxies or extended clouds of gas, or all sorts of things also create natural radio emissions, although they're very, very weak. But with these big giant dishes that they put on the ground and operate as radio telescopes, they can collect enough signal to measure it. So, these are fascinating things being done, very important things being done with weather radiometers and forecasting weather and hurricanes and things, and very important science being done in radio astronomy. But as mentioned, these natural signals are exceedingly weak, and so those types of systems that use the radio spectrum to listen for this very weak emissions, those are particularly sensitive to interference.

Austin was talking a few minutes ago about the tiny amount of leakage that could come out of a cell phone signal because it goes beyond its intended frequency, and the amount of signal that comes out that goes beyond its intended desired frequency can be 1,000 or 10,000 or 100,000 times less than the signal that comes out at the intended frequency. And for the most part, that doesn't have a major impact on other systems in the radio spectrum, but that amount of signal leaking into a band that's used for radiometers on a satellite or leaking into a band used by a radio telescope that's not very far away could completely disrupt the radiometer or radio astronomy observations that are being made.

So, those systems are very sensitive to what we call these out-of-band emissions, and it's a constant battle. The people who operate these satellites and the radio astronomers will tell you that it's a constant battle trying to fight sources of radio interference to their systems. They'll also be the first ones to tell you that a lot of the radio interference they have to deal with comes from themselves. I began life as a radio astronomer and most of the interference to radio telescopes turns out to be caused by electronics that are used to run the radio telescope, and they have to spend a specific, an amazing amount of time tracking down signal leakage and interference coming from the various electronic systems they have at the observatory, but they also have to deal with interference coming from cell phones operating nearby and even satellites overhead that are transmitting signals down and stuff.

And this is such a challenge, by the way. People may have heard that there is what's called the National Radio Quiet Zone, which basically covers a good chunk of West Virginia and part of Virginia and part of Maryland, and it's this big zone, it's not where no radio signals are allowed, but if you want to put certain types of radio transmitters, like fixed radio transmitters that are on a cell tower or whatever, you have to coordinate with one of the major radio astronomy observatories, the Green Bank Observatory that is in West Virginia, and they will run calculations and make sure that the system you're putting up won't cause signals that will disrupt their radio astronomy observation. So, this is this 13,000 square mile area. If you wanted to put up a cell tower, you've got a coordinate with Green Bank and they'll make sure you're not going to interfere with them. So, it's a constant battle, and as the spectrum fills up and there's fewer places for people to do their science and their wireless transmissions and stuff, these interference cases pop up more and more.

Robert J. Marks:

That is fascinating. So, we have to make sure that these radiometers and such are not polluted with all of the application of new frequencies that we're talking about or new uses for the frequency and the greater demand. Really interesting. Okay, new topic. Austin, I know you have some thoughts about this. What is 5G? I hear it all over the place. 5G this, 5G that, some places they're talking about 6G now. What is 5G? I don't know. I'm an engineer, I should know, but I don't know. What is 5G?

Austin Egbert:

The simplest answer is 5G is just basically an acronym standing for fifth generation, and so it's kind of an umbrella term over all of the different cellular communication technologies that have been considered to be under the fifth generation of wireless communication standards. So, 5G implies the existence of earlier G's. You had 1G, first generation. Nobody really called it a generation at that point. It just was cellular communications. Eventually we had 2G, which wasn't really a term that was popular, I don't think, at least I don't recall hearing it at the time. 3G eventually came along. You started hearing things about 3G phones. If I remember right, I think the iPhone, one of the early models of it was branded as the iPhone 3G, kind of in a reference to that third generation of cellular technologies. 4G is maybe more commonly known as LTE. I think a lot of phones will show if you're on a 4G standards network, it will show an LTE near the signal strength.

Robert J. Marks:

What does LTE stand for?

Austin Egbert:

If I remember right, I think LTE stands for Long-Term Evolution. There's kind of been this idea within the wireless industry of they want to move away from these sort of big changes to standards over time, and have set up a situation where they're able to make changes gradually over time rather than just release a whole new standard of a bunch of things in one go. And so that's kind of where that LTE term came from. One of the problems with that that I think some companies are realizing, something I think similar has maybe happened with Microsoft recently, is that if you just change things a little bit over time, you never have a big moment where you can market something new to people. If it's just always getting a little bit better and a little bit better, there's no big marketing push you can make around that.

Something similar happened with Windows. They released Windows 10 and they said, "This is going to be the last version of Windows ever. We're just going to constantly improve it and it'll change over time," and then just here in the last couple of years, we've had Windows 11 show up. So, despite saying Windows 10 was going to be the last version of Windows ever, now we have Windows 11, which they were then able to market as this nice new thing, because it was a lot harder to market, "Oh, here's the biannual update to Windows 10 that's introduced some new things." So, I think something similar happened with going from 4G to 5G, is that everyone went, "Oh, if we just keep changing things, when can we ever say our systems are much better and you need to go buy a new phone to take advantage of all of these cool new things?"

Robert J. Marks:

So, you're saying 5G is largely a marketing ploy?

Austin Egbert:

No. I think what ended up happening is it's one thing to say, "Yeah, we're going to just sort of evolve these standards over time." If you don't have a concrete set of, "Here's the new things," it becomes sort of this mess of organization in a lot of situations where it's like, okay, well, what things do you support? Because as you go on over time, eventually you kind of have to drop support for something. Having those 2G, 3G kind of identifiers has helped with that because cell companies have been able to say, "Okay, we're shutting down our 2G network. We're not going to keep the equipment in the field that supports those technologies. We've moved on to the newer stuff that we would rather maintain." And so if you just, hypothetically, if you were to try and keep everything within LTE long-term, it would become a mess of saying, "Well, what things within LTE do you or do you not support?" So, having an umbrella term can be useful when you want to talk about compatibility of different situations.

So, 5G did end up rolling out, and it has had a significant number of changes within it. One of the main things that's happened is there's been a discussion of millimeter wave 5G. I think, I don't remember the marketing term for that band, but it's essentially they have started trying to use some wider bandwidth signals than had been used in previous cellular technology generations. And so there is actually new stuff in 5G. However, some people may remember early on, I think this was possibly early 2020, AT&T launched what was called 5GE, which they dubbed what they explained as meaning 5G Evolution. And this stirred up quite a bit of controversy amongst consumers and other players in the wireless industry, because 5GE really did have nothing to do with 5G. It was just a rebrand. It was a rebrand of a bunch of things that had happened in LTE, new technologies that had been introduced as early as even 2017.

So, AT&T customers had had the 5GE technologies potentially from 2017 onward, but in 2020 AT&T said, "We want to be the first ones to 5G. 5G currently doesn't exist anywhere yet, but we want to beat everyone else to it. So, we'll slap a new coat of paint on these LTE features and call it 5GE. We'll justify it as being these are technologies moving us on the way to eventual 5G." But I mean, they were pretty widely criticized as it being a blatant marketing grab without much technical substance behind it. So, there's some instances where you have to be careful with what's 5G? What's 6G? Early on in any type of standard, no one really knows what 5G is. But it ends up just being the camp within which everyone just talks about what they want to have happen in the next wireless generation, next cellular generation. We're seeing something similar now with 6G.

You asked what is 6G? No one really knows at this point. There is not a 6G standard that has been established. They're in development, people are trying to figure out what new features and capabilities are we going to try and package together and put into some outcoming standard, but if somebody comes along and tells you, "I know exactly what 6G is going to be. It's going to do this, that, and that," at this point, it's basically just pure speculation, and in many cases maybe just marketing hype. Because, again, everyone wants to kind of be the first to something, because then you can claim, "Oh, I was the first one to have a 5G network." Well, people want to be the first ones to have a 6G network because then that's a big marketing buzzword that they can give to consumers and things like that to try and drum up business.

Robert J. Marks:

That's interesting. One of the things in order to accommodate all of the new users of cell phones is to go to different frequencies. And Andy, I think you were telling me that when this happens, we're going to have to rethink and redo our infrastructure on how we use it, that our current spacing of towers is going to be too far apart. Could you elaborate on that a little bit?

Andrew Clegg:

Yeah, I mean, I think that's yet to be seen still, but as you go to higher frequencies, the signals don't, in general, don't propagate quite as far. In other words, the signal becomes weaker faster. And so especially in the millimeter wave 5G that Austin was talking about, the signals, they typically can't penetrate into buildings, they typically don't bend around corners very well and things like that, like signals at lower frequencies do. And so in the extreme case of the millimeter wave 5G, if you want to have that in a city, you need a cell every block, you need to basically have line of sight. You need to be able to see that cell with your own eyes in order for-

Robert J. Marks:

Okay. So, how far apart today are cell towers?

Andrew Clegg:

So, it depends. If you're in a rural area and they don't need to serve a very high density of customers there, there could be 10 or 15 miles between cell towers in theory. If you're on a flat area and you've got good visibility around you, they don't need to be spaced very closely. But at millimeter wave frequencies, again, sort of the opposite situation, you're in a city with buildings and things, you need to have them basically on every block. And that's very expensive. Not only is the hardware expensive, but you have to have fiber and power and everything run to every one of these base stations in order for them to function. We call that densification. So, you either have to densify because your signals aren't traveling very far, like we have in the case of the millimeter wave 5G, or you have to densify if your users are using a lot of bandwidth, because a given cell tower over the air can only provide a fixed amount of bandwidth to all of the users using that cell tower.

So, if you have too many users demanding too much bandwidth from a tower, some of those users aren't going to be able to do what they want, their videos are going to buffer or whatever, and so you have to put up more cell towers so that you can serve more people in a given area. That's also an example of densification. In that latter case, it's because of the capacity. You need more capacity for your cell network, so you have to put up more cells. In the former case, it's a propagation, it's a coverage-based densification. You need more cells just to be able to cover an area with a usable signal. So, in my opinion, millimeter wave 5G has not been particularly successful because, first of all, the users realize that their signal cuts out immediately upon going into a building or going out of a building tower if the cell happens to be in the building, or just going around a corner, they lose it. And the phones are also, as we mentioned earlier, the phones are less power efficient at those frequencies, so your batteries don't last as long.

So, I don't see millimeter wave 5G as being a big commercial success that's going to be replicated on grand scale in other generations. Now, of course, a lot of people, the big dreamers believe that 6G is going to be about going to even higher frequencies and providing even more bandwidth and being able to send a hundred gigabits per second to a phone. I don't see that as being the driving force, and I think the experience with millimeter wave 5G shows that going to higher frequencies has enough problems that it's probably not the future.

So, I sort of see that the typical cell spacing now of a couple of kilometers or somewhere around there, on average, if you took suburban and urban areas, maybe two or three kilometer average separation between base stations, I would think that that's probably what we're also going to see as 5G evolves, but I guess we'll see. If a killer app comes out that just demands a tremendous amount of bandwidth, augmented reality takes off and people don't mind walking around wearing those crazy looking headsets, maybe we will need more cell sites. But at the moment, my prediction is I don't see that happening in the near term, and who knows what will happen in the longer term?

Robert J. Marks:

That's fascinating. I believe, if I remember right, I saw a startup company that was concerned about the problem with the propagation of these higher frequencies, and so they were developing a technology that you could put, for example, in a window. Now, in a window, I mean you would have to cut out a circle in the window and put this device in it so that the window wasn't in the way, or you could even do it as a wall, and on one side would be a receiver for the signal and there would be a retransmission on the other side, in order to beat some of these problems. So, that was a solution I think that would work, wouldn't it?

Andrew Clegg:

Yeah, not a bad idea. And you mentioned windows. One of the challenges that is occurring basically at all frequencies now is that as buildings are made more energy efficient, a lot of the technologies that make a building more energy efficient are also good at blocking radio waves, and in particular with windows, they will often put a conducting thermal film on the windows in order to keep heat in, or AC in. In other words, to keep what you want on one side of the window away from what you don't want on the other side of the window in terms of heat or cold or whatever. And those same methods of manufacturing windows that make them hold up well to thermal electromagnetic waves going in and out is also blocking radio waves from going in and out.

Robert J. Marks:

Oh boy.

Andrew Clegg:

And so some of these highly efficient buildings have very high attenuation, and it's not just at the higher frequencies. It's basically at all frequencies. And so it's getting harder to serve the inside of buildings with radio cellular signals these days because of the attenuating effects of these types of thermally-efficient windows. Now, a lot of times we don't notice it because we tend to switch over to Wi-Fi or something that's inside the building rather than relying on cell signals, but a lot of the current buildings that are out there, the cell signals just don't penetrate in very well.

Robert J. Marks:

Fascinating. Okay, we're about out of time. Any final thoughts from either Austin or Andy?

Austin Egbert:

I'm good here.

Andrew Clegg:

Yeah, I think I'm good here. Looking forward, it's always hard to predict the future.

Robert J. Marks:

It is.

Andrew Clegg:

But yeah, it'll be fascinating to see what kind of world we're living in and what 6G ends up being 10 years from now.

Robert J. Marks:

There's an old Danish proverb that says, "Forecasting is dangerous, especially if it's about the future." And so that's where we're at right now.

Andrew Clegg:

Totally agree.

Robert J. Marks:

Totally. Okay, great. Hey, we've been talking to spectrum specialist Dr. Andrew Clegg from Google, and Dr. Austin Egbert, who is a research scientist at Baylor University. And so until next time, be of good cheer.

Announcer:

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