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WHAT WILL REPLACE Wi-Fi IN THE FUTURE?

You must admit that our lives would be different without Wi-Fi, because along with mobile communications, this is already our main way of connecting to the Internet. Yes, of course, there are those who use an Ethernet cable, but they are clearly a minority, and even fewer of those who have a modem dialogue – it's just something exotic. Well, over time, the load on Wi-Fi only increases: more and more devices, including vacuum cleaners, light bulbs, speakers and even guitars; more and more applications, more and more difficult content. You won't surprise anyone with 8k video resolution. And *Apple* also released their AR helmet, and now this direction will start to develop! And there, the appetite for traffic is not childish at all. So far Wi-Fi is doing fine in its current form; I think it will last us another 10-15 years. But what will happen when demanding users require speeds of several Gb/s, and all channels are occupied by other devices, because literally everything is connected to the Internet? Will it become even more powerful and even faster? Or has the fundamental limit already been reached, and should it be replaced by some other technology, like satellite Internet? Or maybe even a different physical principle! So, we should find out the fate of our favorite Wi-Fi, understand how to watch YouTube by connecting a smartphone directly to a satellite, analyze such unusual technologies that even Elon Musk could not dream of, and understand what awaits us in the future.

First, let's figure out how Wi-Fi works and what determines its speed? This will make it clearer where its fundamental limit may be. The throughput of a wireless connection depends on many physical parameters, but there are 3 main ones: 1) signal strength; 2) the number of spatial streams; 3) channel width. First things first:

1) the greater the signal-to-noise ratio, for simplicity we will say "signal strength," the more gradations of this signal can be distinguished. And more bits can be transmitted at a time, for example: the Wi-Fi standard of 2000 had 64 gradations (6 Bits in one character), and modern Wi-Fi6 already offers up to 1024 gradations, that is, you can transmit as many as 10 bits at a time. This, of course, is all simplified, because everything is encoded there not only by changing the amplitude, but also the phase. But we won't go into details.

2) Spatial flows. You've probably seen eight-antenna spider routers that have eight antennas around the perimeter; this is the main element of MIMO technology – multiple input/multiple output, which allows you to pull off this trick: different data can be sent from different antennas at the same frequency. Yes, they all get mixed up and it turns out to be a “porridge” of radio waves, in which nothing can be made out. But if the receiving device also has 8 antennas, then each signal can be restored using software from this “mess”. This is possible because the waves from each antenna travel a slightly different path. There they are reflected from something and come, one might say not at the same time. This, of course, requires a lot of computing power, but we get a fair increase in speed: 8 antennas means the Internet has become 8 times faster.

3) Wi-Fi channel width does not work at the same frequency. Its signal is evenly spread over the provided channel, only now this is done not by jumps in purity, but by using several subcarriers at close frequencies, over which data is transmitted simultaneously. They are arranged overlapping, but in such a clever way that in areas of overlap they are in antiphase, cancelled, and do not interfere with each other and others under the carrier, therefore they are called orthogonal. So, the wider the channel, the more subcarriers fit into it and the more information is transmitted per second. The logic here is also simple – the relationship is linear. So, what can be done to make Wi-Fi speed even faster, and it’s not about cutting off the neighbors’ electricity, but how to improve the standard itself?

Right now, the new Wi-Fi7 is coming to replace the current Wi-Fi6 and 6E, so it’s convenient to consider this example. You can increase the number of signal gradations. In Wi-Fi7 there are four times as many, up to 4096, which is 12 bits at a time, and why can't we go on like this indefinitely? The fact is that for this you need a high signal-to-noise ratio, and this either comes closer to the router, or increases the power of the radiation itself. But no one wants to carry a microwave in their pocket, so you can't increase speed much like that. You can increase the number of spatial streams (Wi-Fi7 supports up to 16 of them), and if you can use all 16 in laptops, well, most likely it will be possible, but with smartphones it's more difficult, because there are already a lot of antennas for mobile communications (Bluetooth, GPS). And even if you manage to place about 20 of them inside, then do not forget that the threads are separated by software, and this is not a bad load on the hardware and a drawdown in terms of autonomy. So, of course, it is possible to increase the number of spatial streams, but this is a problem with an asterisk. And the width of the channel remains. In the first versions of Wi-Fi there were 14 of them at 20 MHz. But so that they do not overlap, only three can be used. Then they added another 25 channels in the 5 GHz range and allowed them to be combined in groups of four. But then there were only six such wide channels left, so, not too many. The Wi-Fi 6E specification added another range – 6 GHz with sixty channels, and in Wi-Fi7 they can be combined in 16 pieces. In general, there are a lot of numbers, so let's just summarize: the maximum channel width will be 320 MHz, it is not clear what to compare this figure with, for example: 1600 FM radio stations fit into this range. In general, this is really a lot, and if all other Wi-Fi7 parameters are also taken to the maximum, then it will be capable of reaching speeds of 46 gigabytes per second. For comparison, this is the same speed as very good SSD drives, just without wires. Of course, such figures are only possible under ideal conditions; on powerful equipment and in typical scenarios, the speed will be lower. Because not all frequencies are available in all countries, and there may be many subscribers, and they will share this speed among themselves. But anyway, this Wi-Fi will most likely be enough for us for 10-20 years [1].

But what happens next? There is a difficult way: increase the number of spatial streams, the number of signal gradations, you can even place subcarriers closer. Then they are called non-orthogonal, and to separate them requires even more calculations. But there is an easy way: just add even more channels. There are many free windows at frequencies of tens of gigahertz. And most likely, they will be gradually occupied by new Wi-Fi specifications. So, at least 100, at least 200 gigabits per second, I think, will not be any particular problem. Yes, the range will suffer a little, but just put not one router in the apartment, but several, and the problem is solved. So the potential of Wi-Fi technology is extremely impressive, and we are definitely with it for a long time.

Let's imagine that in the future we won't need Wi-Fi at all, and it will be completely replaced by mobile communications. After all, now with 4G, we don't look for Wi-Fi in cafes. And when 5G becomes widespread, will we need all sorts of home routers and access points? It's hard to say. On the one hand, wireless traffic is now quite organically distributed between mobile communications and Wi-Fi. And if one disappears, the other is unlikely to bring in a flow of new connections. At this stage, for sure. In addition, if Wi-Fi allows you to create many networks on one channel that do not interfere with each other, because its range is short, then cell towers have much greater coverage, and if the channel has already been occupied, that's it. Wait for the rest to be released. But on the other hand, new generations of networks have ever wider channels, more and more complex modulation and, accordingly, the frequency range is used more efficiently. And with beamforming technology, many users can sit on the same channel at the same time without disturbing each other. So there are all the prerequisites that after some time we will not have routers at home. It is not yet clear exactly, but such a scenario is quite reasonable. In this case, we need to talk about the development of the mobile Internet. And here, too, everything is interesting, because there are already so many towers. And what can be done to make them more accessible? Of course, raise it higher.

This is what Google's "*Loon*" project did: providing the Internet in rural and remote areas, where direct transmitting equipment was placed on high-altitude pseudo-satellites. What are these pseudo-satellites? These are unmanned aircraft or balloons that fly for a long time without landing in autonomous mode, at an altitude of 20 to 50 km. Specifically, in this project, geostationary balloon pseudo-satellites were used. Giant fifteen-meter balloons filled with helium, hanging over one point above the ground. The equipment on them was powered by a 100 W solar panel, which also charged the battery for night work. The balls had to exchange information with each other using lasers, and the service life of each was more than 200 days. The most interesting thing was how it was proposed to keep the balls in place, because they were not tied to a string. It is known that at different altitudes the wind blows with different strengths, and often in different directions. The balls are equipped with a system capable of changing their volume, that is, buoyancy, and so they can rise and fall, just like a fish squeezing and unclenching its swim bladder. Therefore, using artificial intelligence, deftly maneuvering between layers with the desired wind, you can drift near one point. So, perhaps, soon all cellular towers will disappear in cities and beyond, and their place will be taken by "communication balloons" [2].

Pseudo-satellites are good, of course, they are not expensive to develop and maintain. But if we want global coverage, we need real satellites. I think everyone has heard about Starlink, and this is not surprising, because it is a very promising technology. But there is one nuance here – you cannot connect your phone to the satellite without a special terminal to receive the signal. And it's necessary to say about a method that allows you to connect a smartphone like yours directly to a satellite without any modification or terminal for receiving the signal. Yes, and this is already possible. Let's figure out what's the problem with connecting a regular phone directly to a satellite? It's all about the size of the phased array antenna, the larger it is, the more focused the beam it can produce, and accordingly send, this produces a more powerful signal per unit area and receives weaker ones. Because the grille is focused at a small angle and does not perceive all the noise around it, it's as if you are talking to someone through a long pipe, which just cuts off everything unnecessary. So, if the area of the antenna array is several tens of square meters, this is enough to receive a weak signal from mobile phones at an altitude of 500-600 km. And it turns out that if you launch the right satellites, your mobile phone automatically turns into a satellite phone. And this is not a dry theory; several companies are already developing satellite communications for ordinary, unmodified phones. "*The Linklobal project*" has already demonstrated a successful voice call from a phone directly via satellite at regular GSM frequencies. And it begins to deploy an orbital constellation for global coverage. The interesting thing is that in addition to physical problems such as: Doppler frequency shift, they had to solve difficulties with the communication protocol, because GSM phones are disconnected from towers that are further than 35 km. And the satellite has to pretend that it is a stationary tower at a distance of 20 km [3]. In June 2023, AST SpaceMobile announced direct data transfer from phone to satellite via LTE at a speed of 10 Mbit/s. This was achieved due to an antenna array measuring 64 m^2, which was unfolded in orbit. And although this is only testing for now, it is proof that it is possible to distribute the Internet from space, and that there are no longer any physical and technical limitations [4].

Well, don't you think it's cool that we are witnessing how rapidly the world of telecommunications is developing! Just some 15 years ago, Wi-Fi had just appeared in phones. And we, of course, had to send something heavy through a wire. And what will happen in 15 years is even difficult to imagine. In general, we are witnessing a great telecommunications leap that is pushing us into the future!

REFERENCES

1. Electronic Wiki article about Wi-Fi and its work [Electronic resource]. Access mode: https://uk.wikipedia.org/wiki/Wi-Fi
2. Project "Loon" from Google – article by K.S.U.I. and C.T. [Electronic resource]. Access mode: https://duikt.edu.ua/ua/news

3. Project “Linklobal” [Electronic resource]. Access mode: https://linkglobal.io
4. Project of the company “AST SpaceMobile” [Electronic resource]. Access mode: https://ast-science.com

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MODERN SCIENTIFIC PROBLEMS OF CYBER SECURITY

The results of war in cyberspace are decisive for the general development of combat operations in modern confrontations. A cyber attack and cyber intrusion can cause massive damage or significant disruption to critical information infrastructure at any level. This applies primarily to cyberattacks on energy, transport, and military infrastructure facilities, during which facilities for supply management, logistics management, etc. are disabled.

We have been observing such attacks throughout the entire period of confrontation with the Russian Federation, starting in 2014. Everyone remembers how at the end of 2015 there were cyber attacks on infrastructure facilities of the energy sector in the Carpathian region and in the Lviv region, as a result of which entire regions remained without electricity and it took some time to restore the network. On the night of the large-scale military invasion of the Russian Federation on the territory of Ukraine on February 24, 2022, a massive attack was carried out on Ukrainian networks, but thanks to cyber protection measures taken in advance, its consequences were minimized. Recently, there have been prolonged attacks on banking institutions, which did cause damage, but due to the rapid response of cyber defense systems, these losses were not as significant as they could have been. Attacks were also observed on the websites of state institutions and central authorities, as a result of which attackers placed provocative advertisements on them or disabled them with the help of so-called DDoS attacks.

The main means of a cyberattack are related to the use of malicious code and attempts to intrude using system vulnerabilities. Malicious code most often enters the system due to violations of cyber hygiene by users – switching to dangerous sites, opening attachments in suspicious e-mails, and therefore the degree of success of the intrusion is determined by the quality of the protection system.