OULUN AMMATTIKORKEAKOULU

Energy Consumption and Emissions of Data Networks

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Energy- and environment technology

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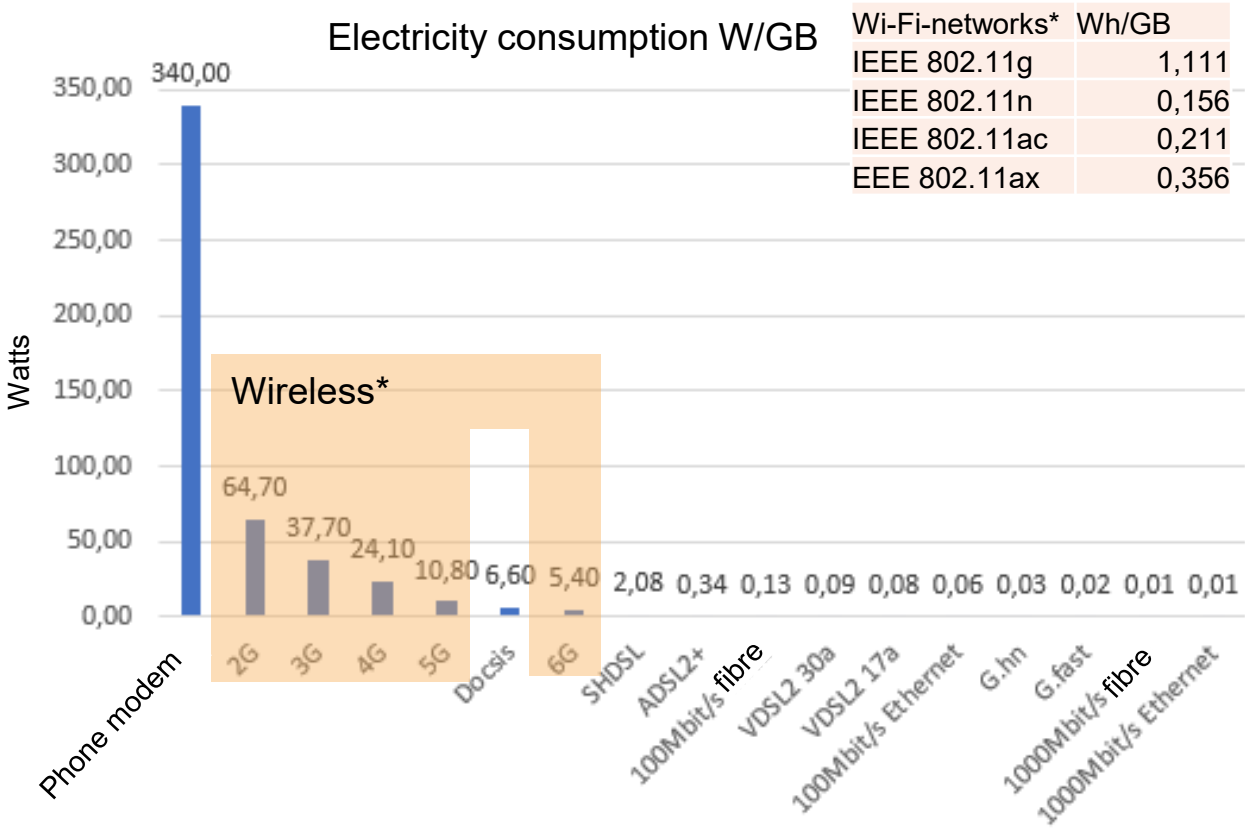
Data sources

- Survey for Finnish telecom operators.
- Own measurements and tests.
- Discussions with those who have worked and are working in the field.
- The results are mainly based on the year of 2021 ”Code of Conduct on Energy Consumption of Broadband Equipment” report of the Joint Research Centre (JRC): https://publications.jrc.ec.europa.eu/repository/handle/JRC125961
- Numerous other public materials and studies.

Electricity consumption of different type networks



Wi-Fi-networks*	Wh/GB
IEEE 802.11g	1,111
IEEE 802.11n	0,156
IEEE 802.11ac	0,211
EEE 802.11ax	0,356

*Wireless technologies do not include the electricity consumption of the terminal device.

Netflix:

Data used per hour, per device:

1. **Low**: Basic video quality, up to 0.3 GB
2. **Medium**: Standard video quality, up to 0.7 GB
3. **High**: Best video quality:
   - Standard definition: up to 1 GB
   - High definition: up to 3 GB = *~7 Mbit/s*
   - Ultra high definition (4K): up to 7 GB = *~16 Mbit/s* (1)

Spotify:

- Normal: 0,096 Mbit/s = 0,04 GB/h
- High: 0,16 Mbit/s = 0,07 GB/h
- best: 0,302 Mbit/s = 0,15 GB/h (2)

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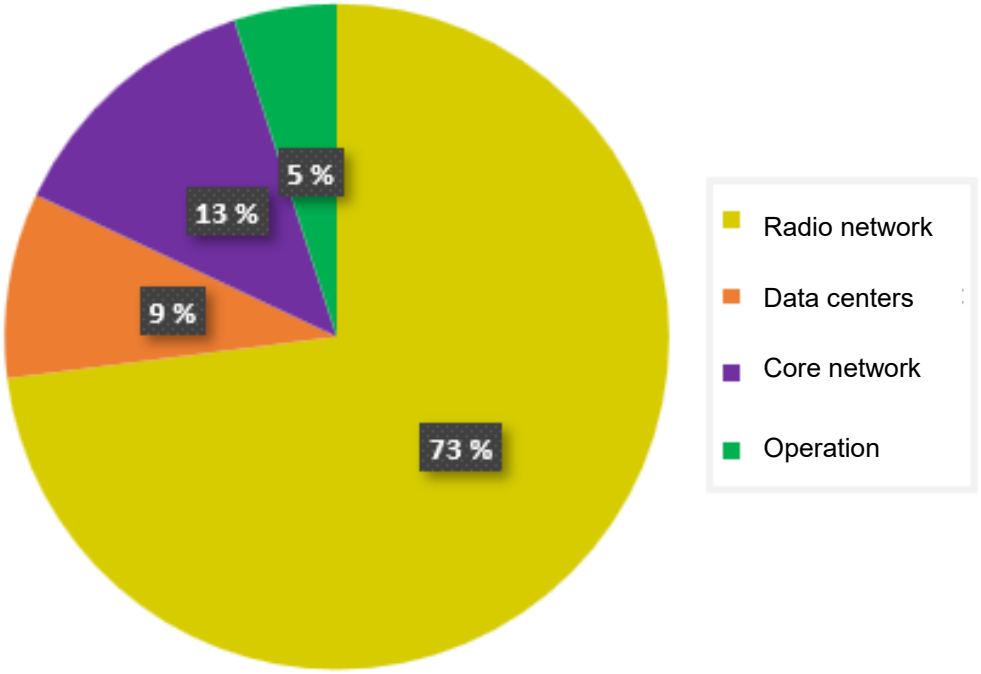
1: https://help.netflix.com/fi/node/87

2. https://www.dailydot.com/upstream/how-much-data-does-spotify-use/

Mobile phone operator's electricity consumption

- Different technologies consume different amounts of electricity with different bandwidths.
- When using a larger bandwidth, electricity consumption can be reduced in proportion to using a smaller bandwidth and several transmitters.
- For example:
  - 2G base station (5 MHz) 172,4 W
  - 3G base station (5 MHz) 357,5 W
  - 4G base station (5 MHz) 390 W
  - 4G base station (20 MHz) *1000 W (1500 W)*
  - 5G base station (100 MHz) *3000 W (5800 W)*

  = Total: 4 919,9 W (8 219,9 W)
- Electricity consumption is greatly influenced by the components used and their energy efficiency, with old components the electricity consumption can be even several times higher. Especially if each technology is implemented with its own devices separately.



https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=60621137&file=300621-Going-Green-efficiency-mobile.pdf

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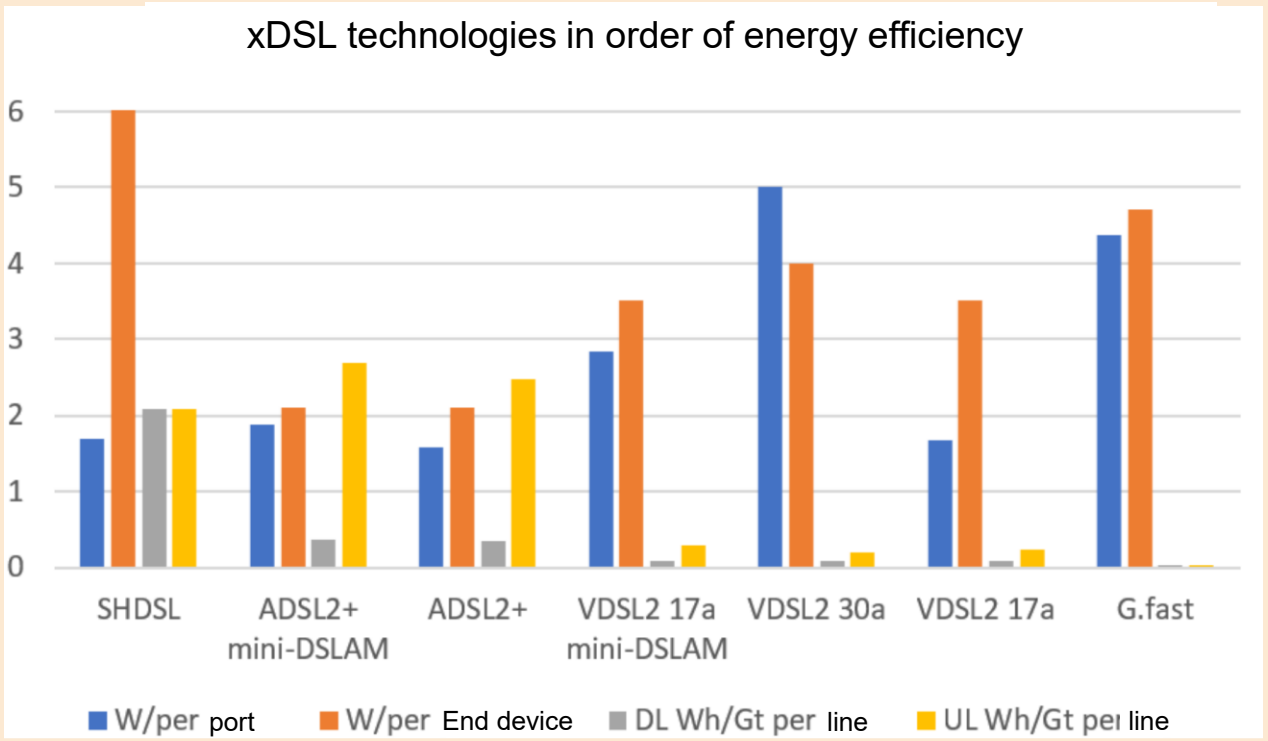
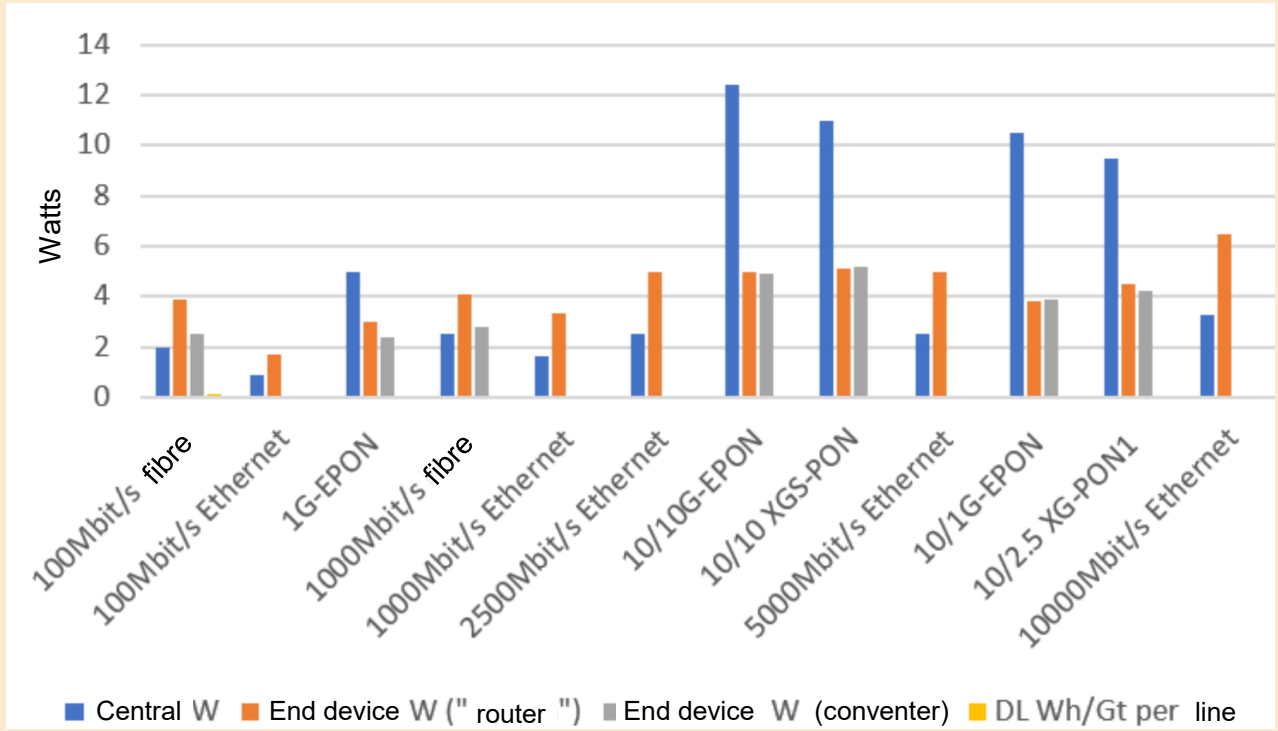
Electricity consumption of devices in the fixed network





The faster the technology, the more energy-efficient the data is transferred, but faster technology consumes more electricity to keep the connection on.

In asymmetric connections, the effect of slower transmission speed on energy efficiency is emphasized.

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Energy efficiency of Fixed Network equipment

- The age of the device does not indicate energy efficiency (an old device can be energy efficient).
  - Number of ports (the more ports, the more energy efficient if the ports are in use).
  - Features (capacity, POE, WLAN, etc. minimize the number of unnecessary features).
- The faster the connection, the more energy efficient if there is a need for a faster speed.
- Asymmetric speed worsens energy efficiency, especially in terms of transmission speed, if there is a need to send a lot of data.
- Fiber optic vs copper Ethernet, no big differences in power consumption (depends a lot on the components used).
- Fiber optic PON technologies are the most energy-efficient if they can be used to provide enough capacity, especially when there are many terminals behind one port.
- Power savings make it possible to use even faster connections with a small load almost as energy-efficiently as slower connections (the appropriate speed is still the most energy-efficient solution if the technology used is energy-efficient in that speed category).

With the electricity consumption of one 4G base station, hundreds of fixed network customers can be served, as well as enabling multiple capacity.

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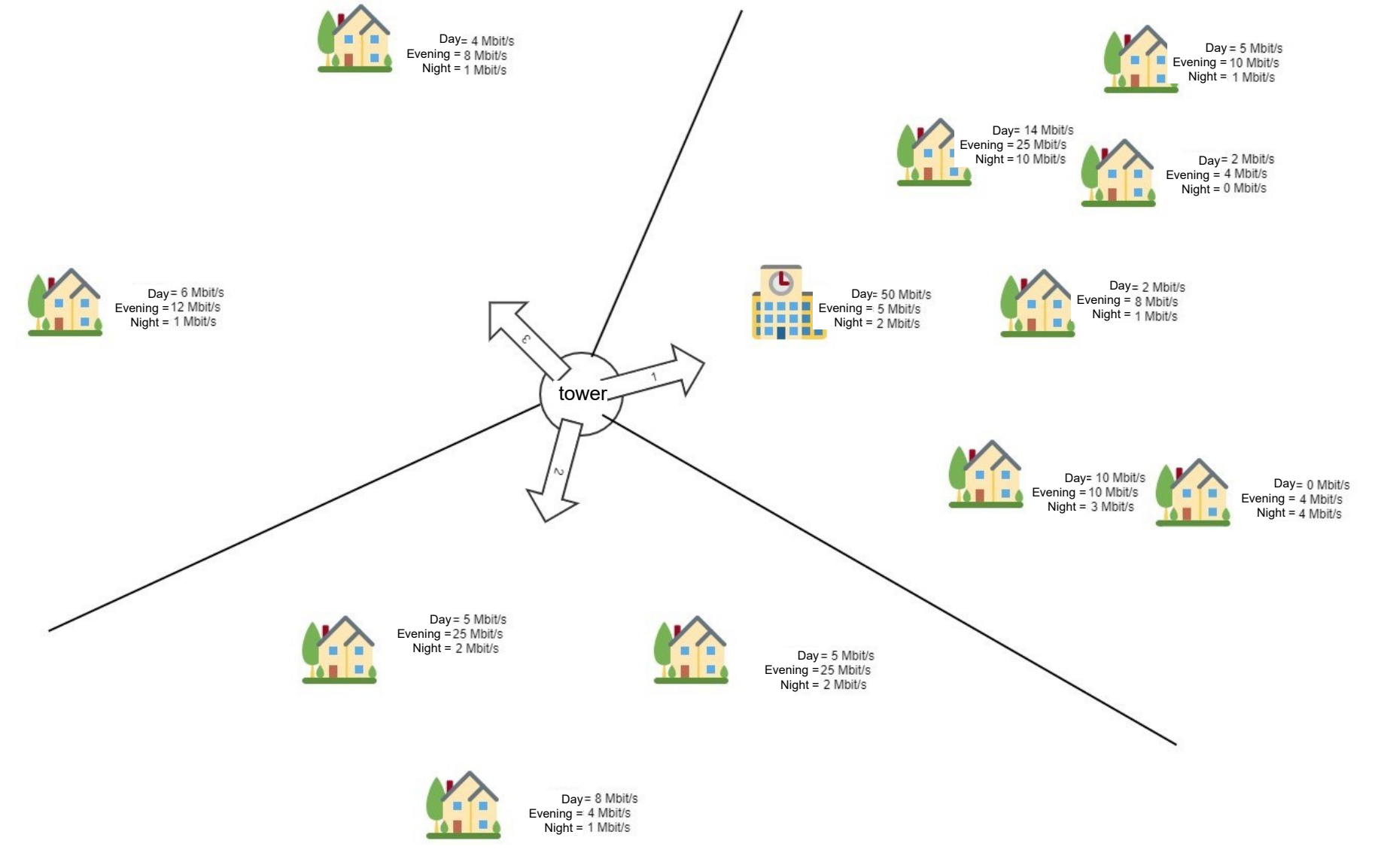
Errors in the example calculations:

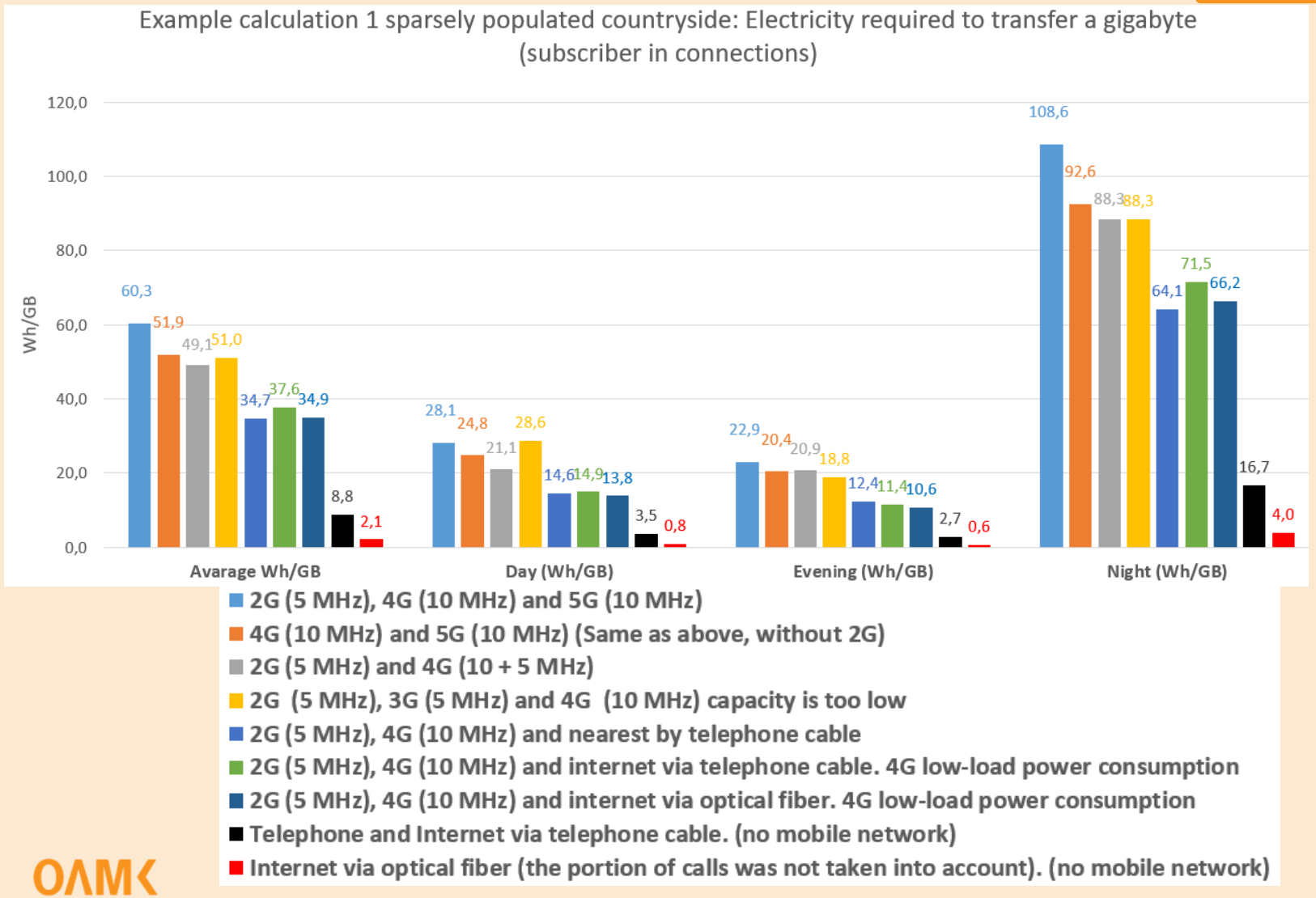
- **For the wider bandwidths of the mobile phone network, the electricity consumption multiplied by example.**
  - 4G base station (20 MHz): 390 W * 4 = 1560 W
  - 5G base station (100 MHz): 390 W * 20 = 7800 W
- **The following things were not taken into account:**
  - Backup power devices (efficiency e.g. 80-98%).
  - Building technology (cooling, lighting, ventilation).
  - Possible core network components.
  - Telephone traffic and the load it brings to networks other than landlines and 2G networks (in the calculation, the majority of calls go through 2G networks).
  - Possible other factors that cause a decrease in speeds (reflection, crosstalk, gaps, etc.), they are, however, partially taken into account as a decrease in connection speed, which, however, corresponds to greater electricity consumption at a faster speed, and an effort was made to choose the technology to be used and the frequency range according to the distance.
  - Other telecom companies (in the example there is only one telecom company, the equipment of other telecom companies is not in the same telecom space, even though in reality the premises and the mast are probably shared by two or more telecom companies).

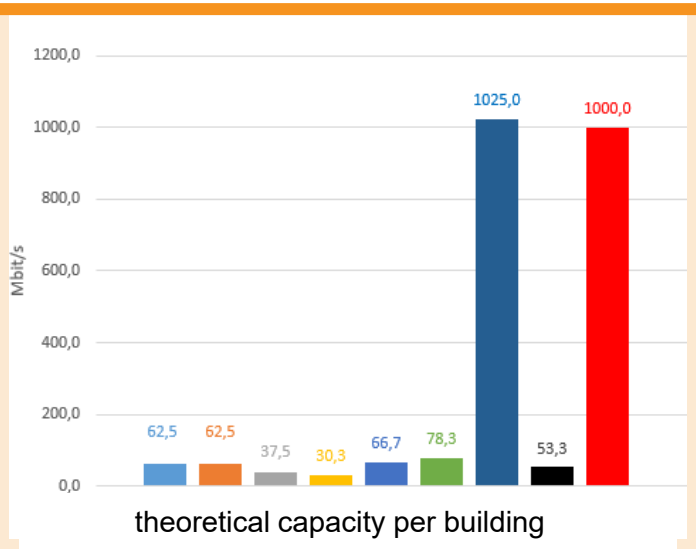
Rural example calculation



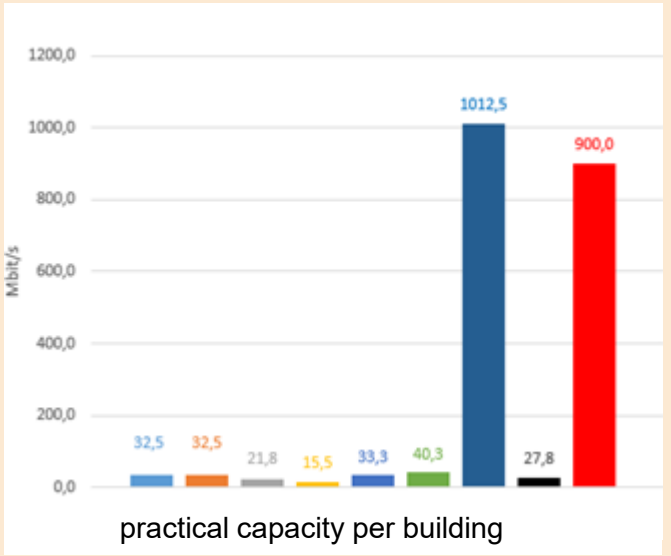
Rural example calculation

Gigabytes transferred on average: **84GB/h**. So a change of one watt affects electricity consumption by **84 Wh**, or about **2 kWh per day**.





theoretical capacity per building



practical capacity per building

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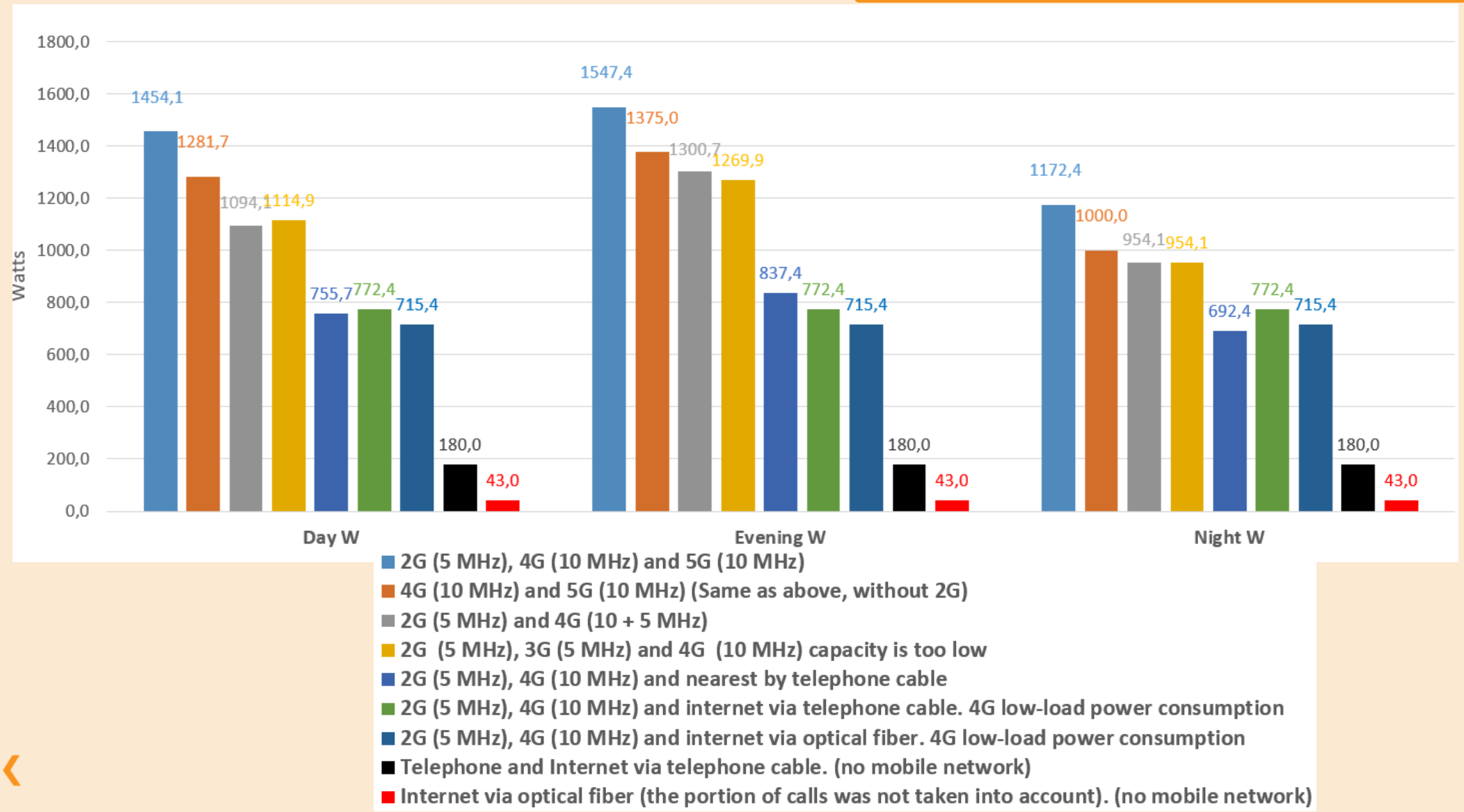
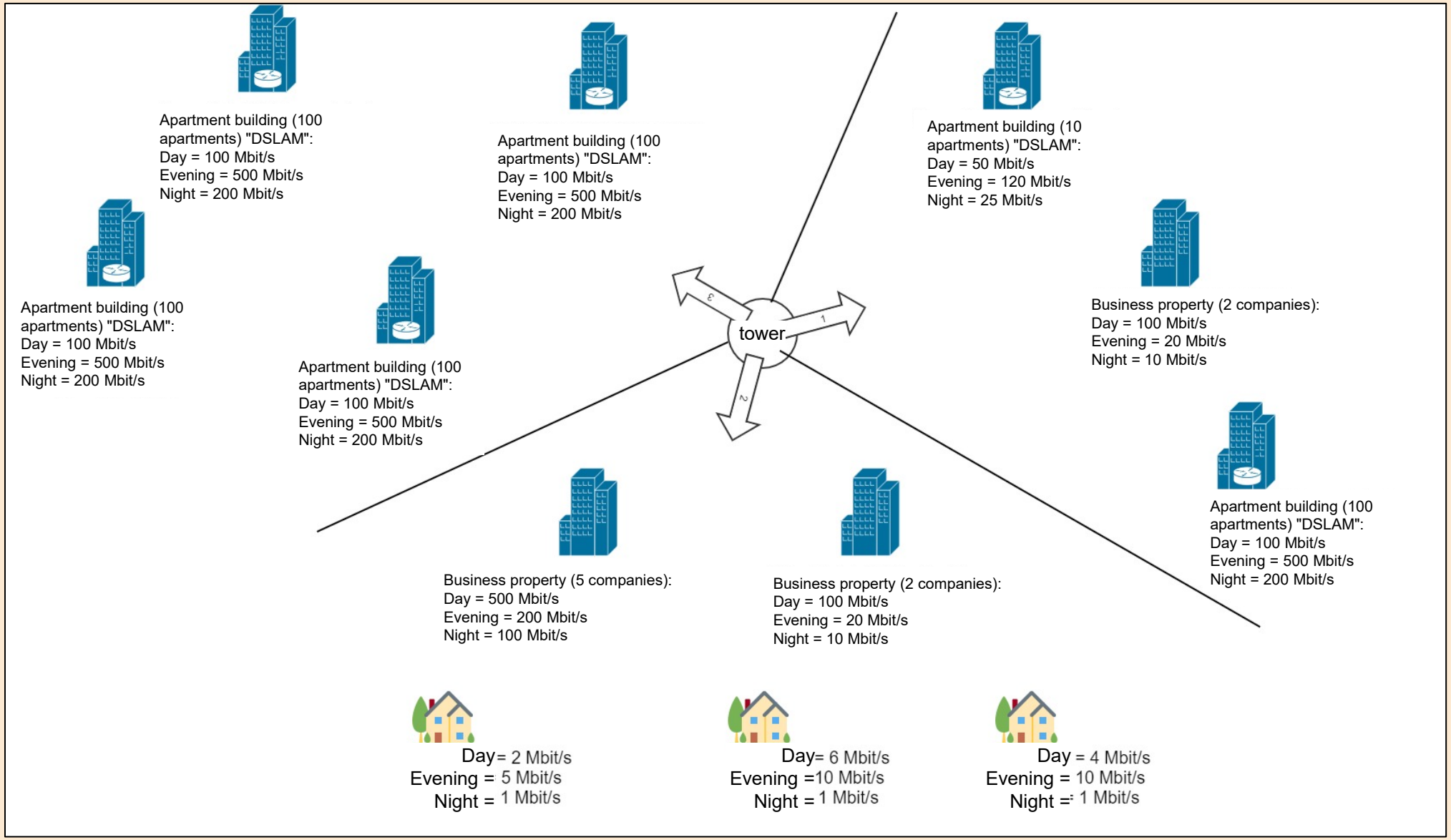
Rural example calculation

Electricity consumed by telecom equipment. The actual electricity consumption of the entire telecentre is higher.

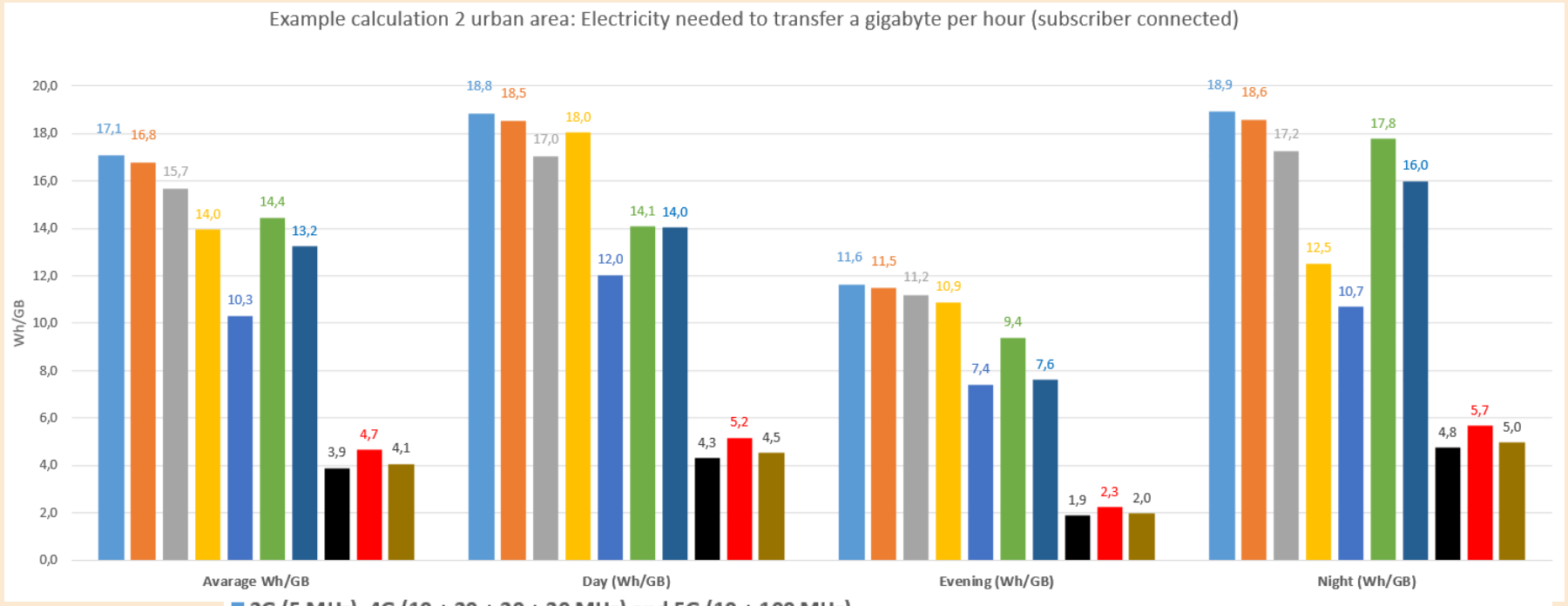


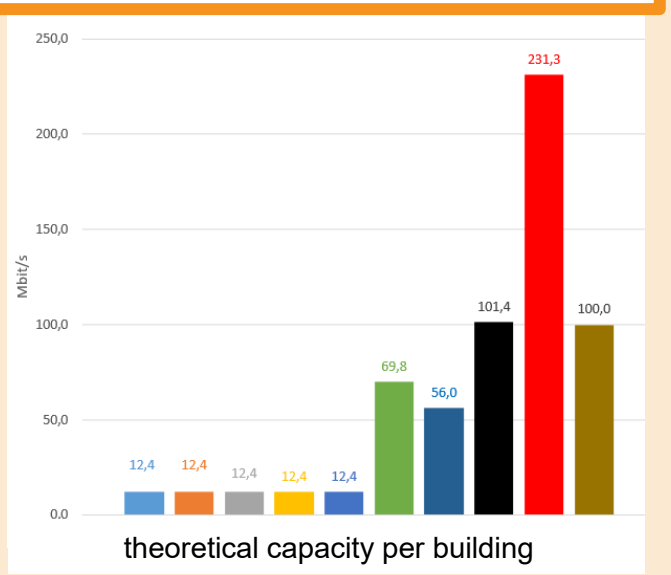
Urban area example calculation



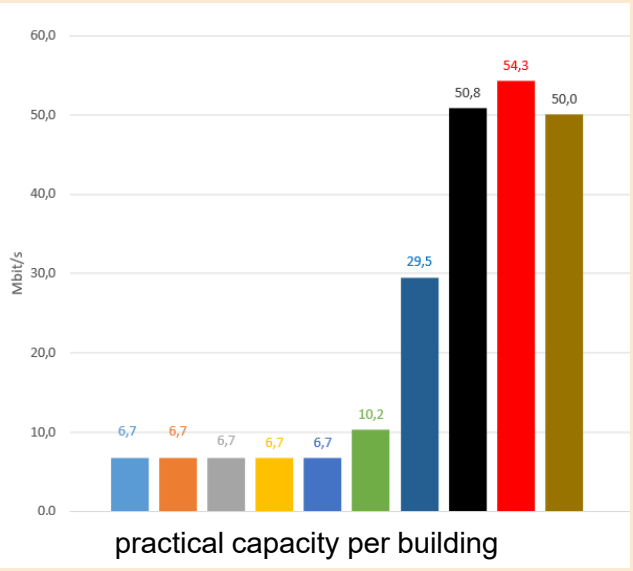
Urban area example calculation

Gigabytes transferred on average: **1620GB/h**. So a change of one watt affects electricity consumption by **1,62 kWh**, or about **39 kWh per day**.





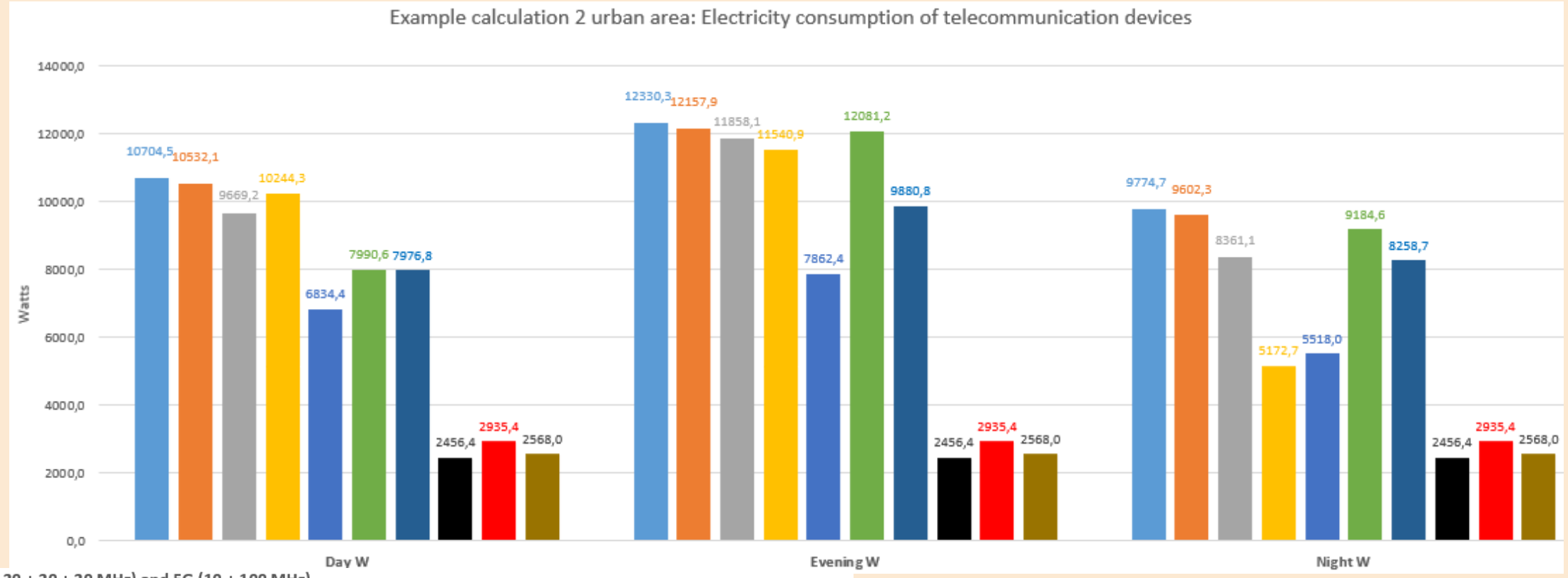
theoretical capacity per building



practical capacity per building

Urban area example calculation

Electricity consumed by telecom equipment. The actual electricity consumption of the entire telecentre is higher.



- 2G (5 MHz), 4G (10 + 20 + 20 + 20 MHz) and 5G (10 + 100 MHz)
- 2G (5 MHz), 4G (10 + 20 + 20 + 20 MHz) and 5G (10 + 100 MHz) (Same as above, without 2G)
- 2G (5 MHz), 4G (10 + 20 + 20* + 20* MHz) and 5G (10 + 100 MHz) *4G shutdown when small load
- 2G (5 MHz), 4G (10 + 20 + 20 + 20 MHz) and 5G (10 + 100* MHz) *5G shutdown when small load
- 2G (5 MHz), 4G (10 + 20 + 20* + 20* MHz) and 5G (10 + 100* MHz) *shutdown of individual cells
- 2G (5 MHz), 4G (10 + 20 + 20 + 20 MHz) and 5G (10 + 100 MHz) + fixed connection to three properties (fiber and, if necessary, DSLAM)
- 2G (5 MHz), 4G (10 MHz) and 5G (10 MHz) + fixed connection to the nearest properties (fiber and, if necessary, DSLAM)
- 2G (5 MHz), 4G (10 MHz) and 5G (10 MHz) + via telephone cable to all VDSL2
- 2G (5 MHz), 4G (10 MHz) and 5G (10 MHz) + fiber + DSLAM in six properties
- No mobile phone network and phone cable, internet + phone.

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Conclusions of the example calculations

- **Using a fixed network saves electricity.**
  - **Optical fiber primarily because it is the most energy efficient and also enables future speeds.**
  - **Secondarily, the copper network (telephone network) with lengths of less than a kilometer.**
    - With G.hn technology, you can get speeds of about 100 Mbit/s from the copper network with a line length of one kilometer using two pairs. Tested with aerial cables to get about 250/200 Mbit/s over a distance of 800 meters.
    - At longer distances, the use of a copper network for data traffic is questionable nowadays. The alternatives remain ADSL2+ or SHDLS, i.e. the speeds remain below 20Mbit/s unless several pairs are used and e.g. load balancing between two connections, of course ADSL2+'s 10Mbit/s is still enough to watch a Full HD (1080p) picture, which is enough for most people.
    - **Telephone network repair debt and old paper/wire insulated cables can make the connection unusable.**
  - **Longer distances via coaxial cable or destinations where the quality/capacity of the telephone network is insufficient.**
    - If there is a need for TV channels, coaxial cable should be preferred instead of the telephone network.
- **Mobile phone network primarily for calls and mobile use.**
  - Secondary for Internet traffic, if it is not possible to implement a fast enough connection via a fixed network or the distance to the center is long (more than a kilometer).

Conclusions of the example calculations

- In the mobile phone network, it is difficult to guarantee sufficient capacity and quality for users, without a dense network of base stations. In these examples, in some cases the capacity of the mobile phone network runs out. Even when taking into account calls and other devices in the mobile phone network, the capacity will probably run out even worse in the middle and the connection will therefore be unusable.
- Existing users must not be forgotten, they must have the opportunity to get at least a similar quality connection, can the mobile phone network be able to do that? There are technical challenges with, for example, capacity, delay and IP addresses.

EU directive 2018/1972. Article 81*: "Migration from legacy infrastructure"*

"appropriate notice period for transition, and establishes the availability of alternative products of at least comparable quality"

"making available an alternative access product of at least comparable quality as was available using the legacy infrastructure enabling the access seekers to reach the same end-users"

If the conditions are not met, the supervisory authority can prevent the destruction or replacement of the network. (There are no resources for supervision in Finland (enlightened citizens supervise)).

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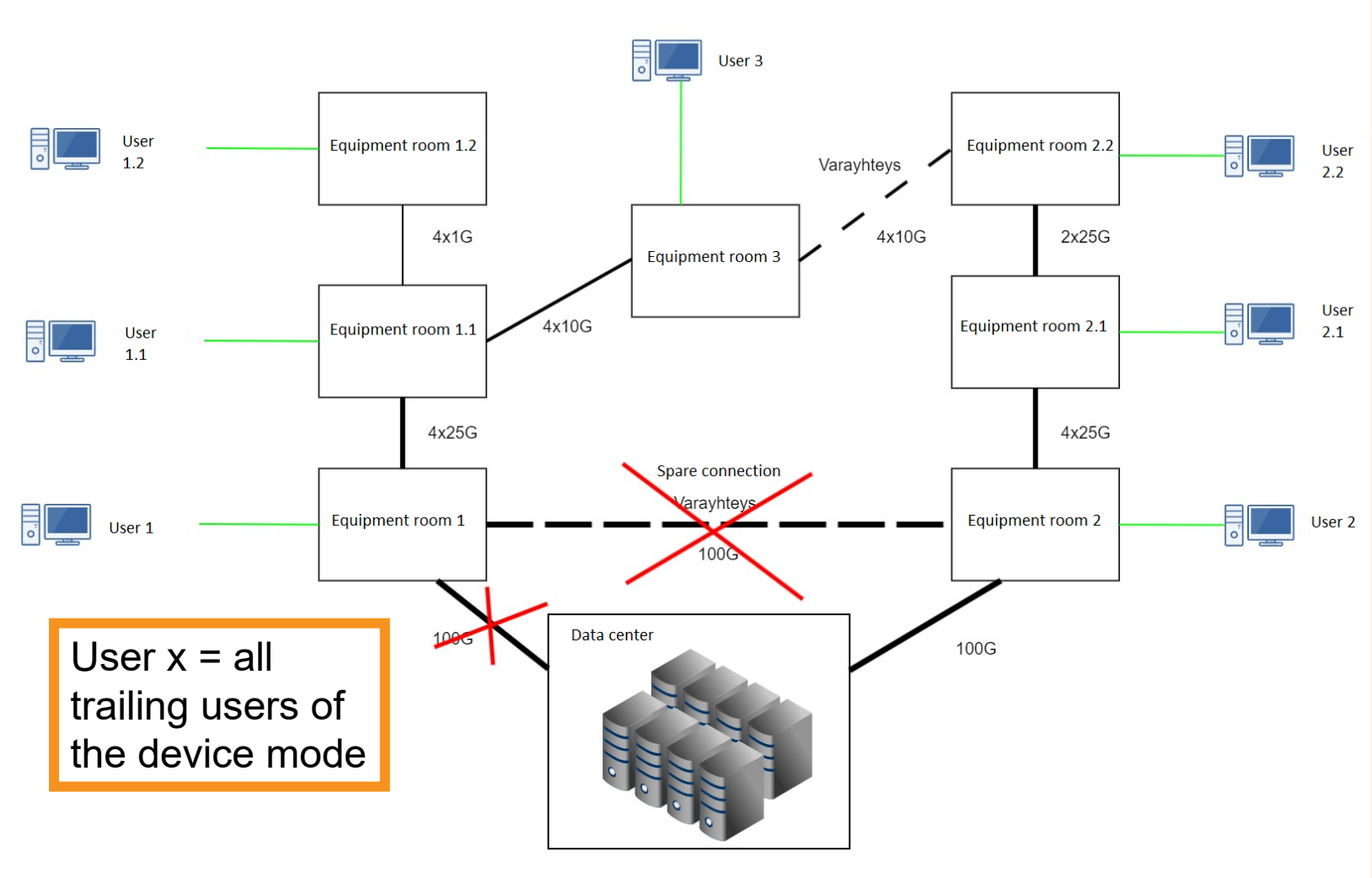
Example calculation of the backbone network

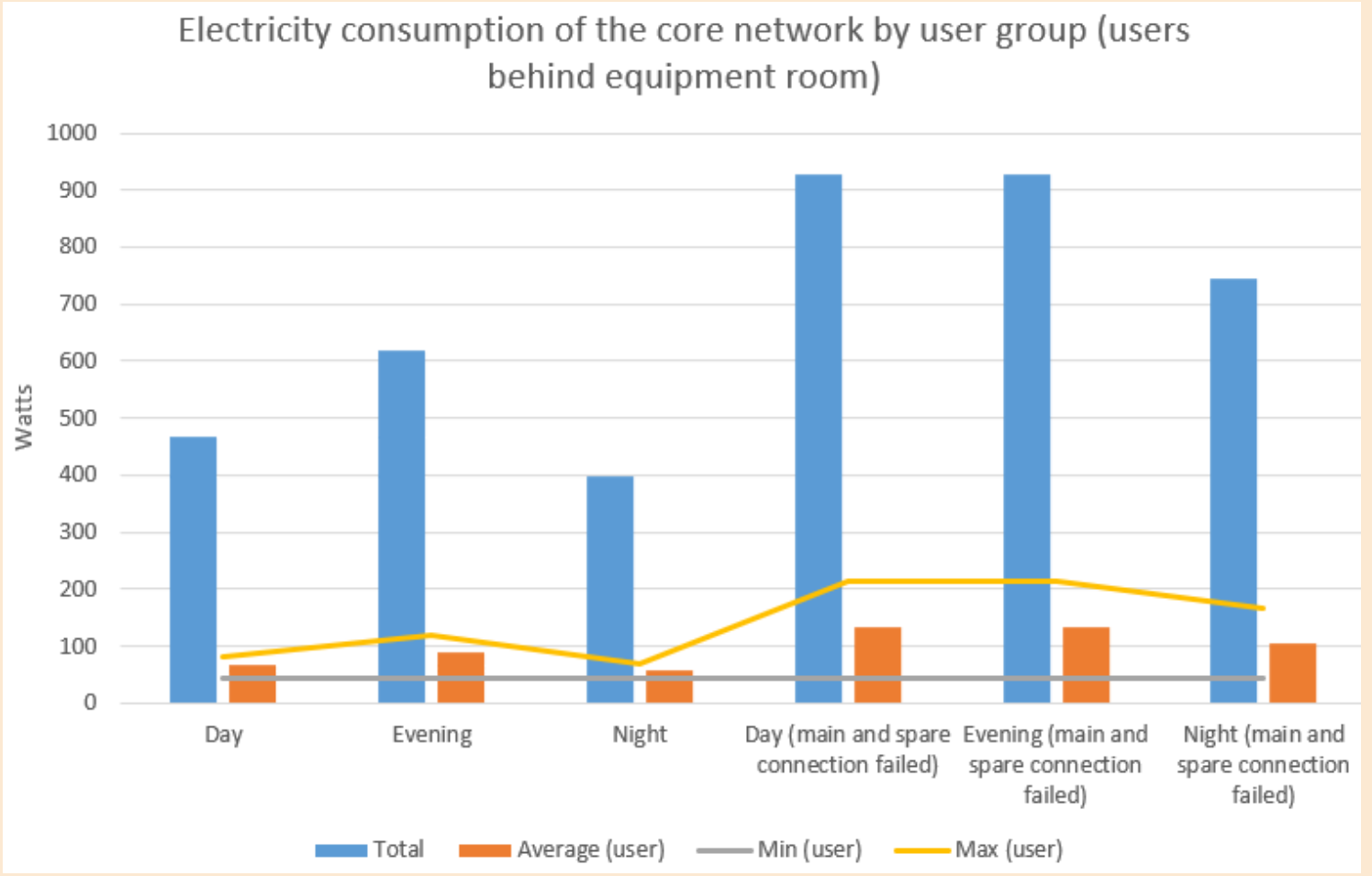
- Let's calculate how the load on the network affects electricity consumption, when you can turn off or turn on fiber optic connections as needed.

- Let's calculate how electricity consumption changes if the end (marked in red) and the backup connection fail.



Example calculation of the backbone network

- With the help of several optical fiber links with a lower speed, electricity can be saved by switching off some of the links according to the load level of the network.
- The faster the fiber optic link, the more energy efficient, but the higher the electricity consumption at low load levels.
- Electricity consumption increases if the connection goes through several nodes.



Load levels:
- Day 50%
- Evening 80%
- Night 20%

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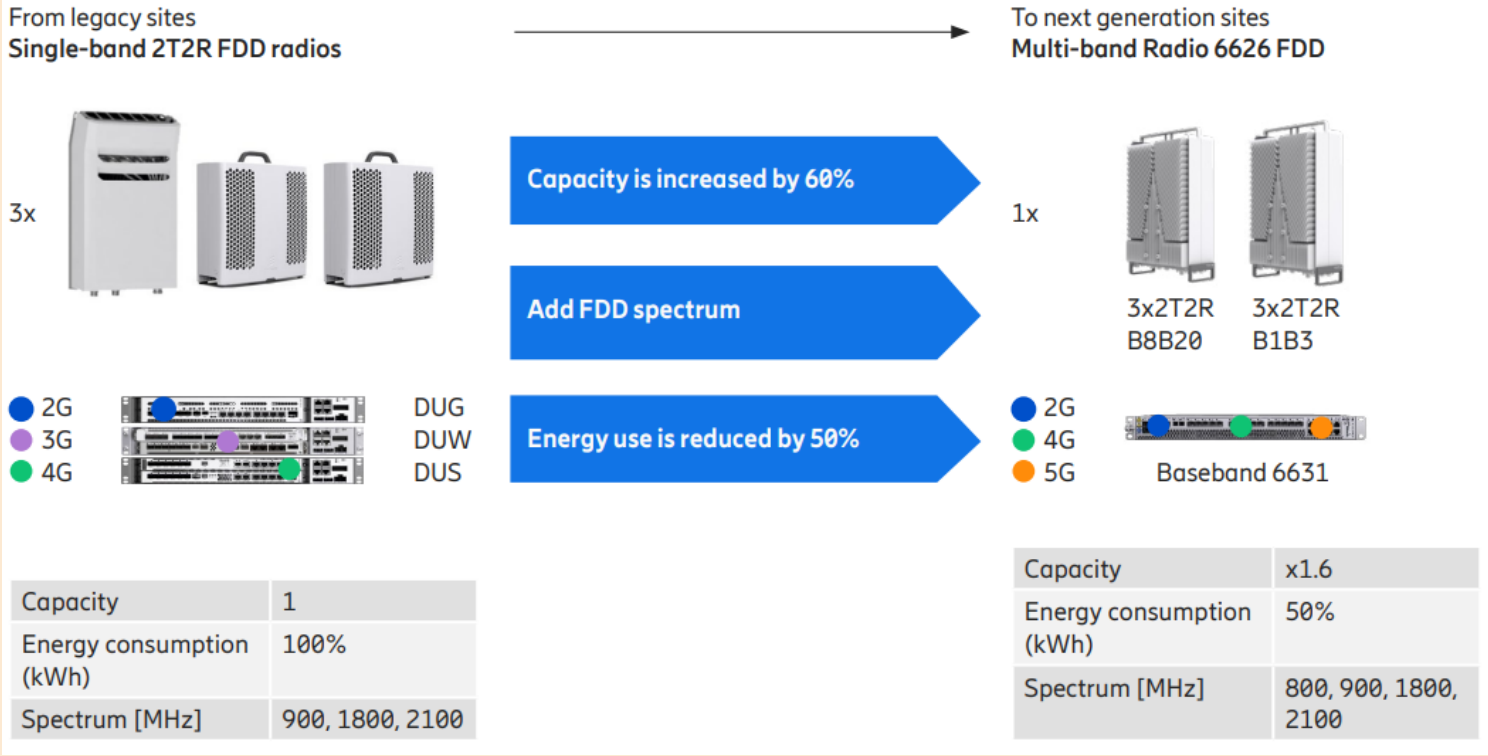
Development of electricity consumption of mobile phone networks

Electricity consumption has decreased with the help of more energy-efficient mobile phone network components. The efficiency of radios in particular has increased and at the same time electricity consumption has decreased a lot. **Radios consume the most electricity of the cellular network components**.

Multi-band radios can be used to achieve significant energy savings, as well as to offer several generations of different mobile phone networks in an energy-efficient manner.

Figure 5: Site expansion and modernization – adding FDD spectrum



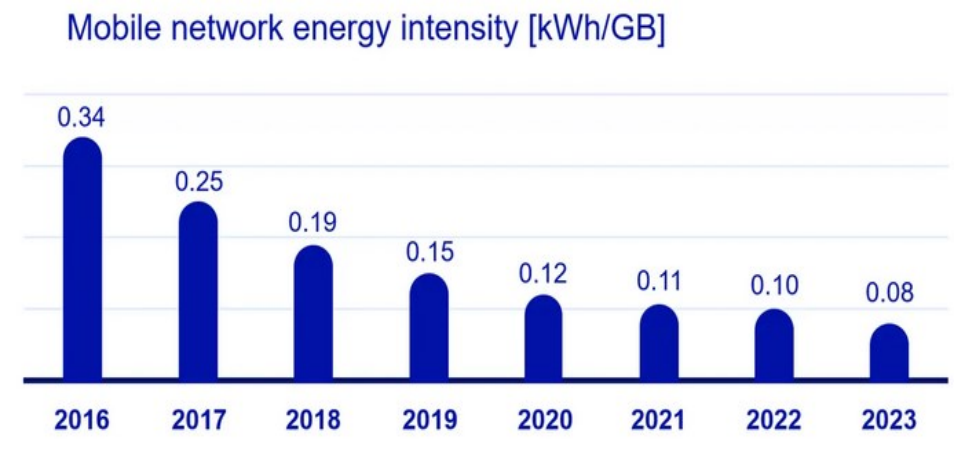
Capacity	1
Energy consumption (kWh)	100%
Spectrum [MHz]	900, 1800, 2100

Capacity	x1.6
Energy consumption (kWh)	50%
Spectrum [MHz]	800, 900, 1800, 2100

(1)

1: Ericsson

Development of electricity consumption of mobile phone networks

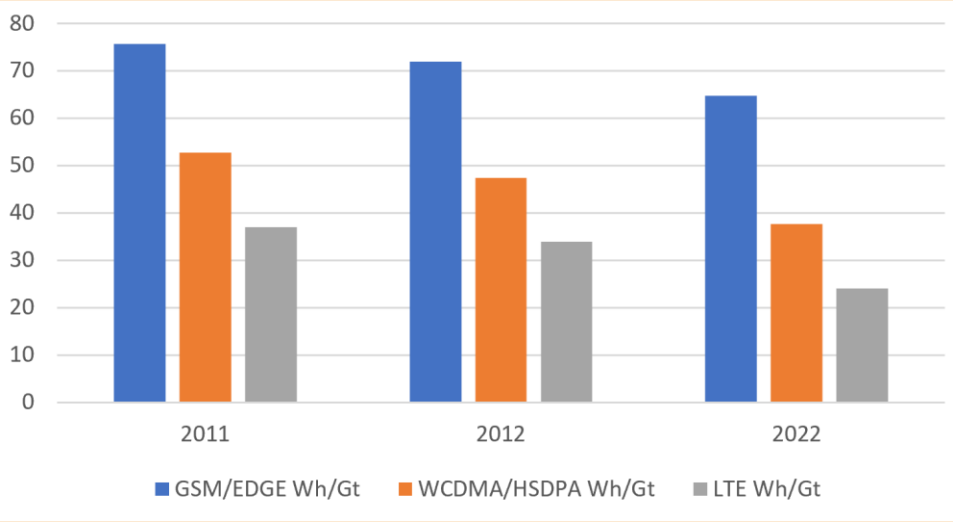


(1)

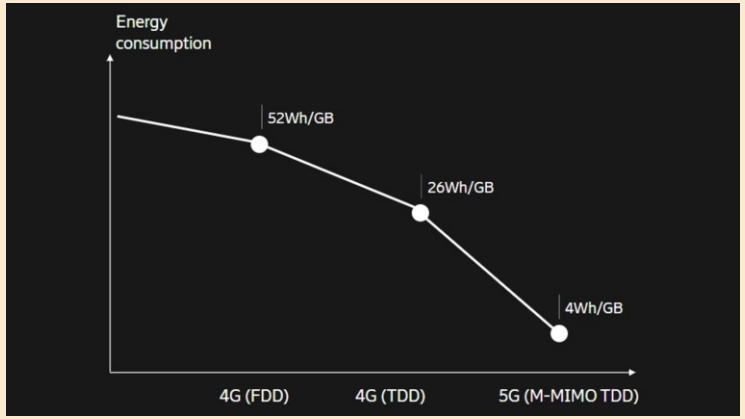
Telia (Finland) 2022 estimated (low frequencies not included):
4G: 0,117 kWh/GB
5G: 0,501 kWh/GB

(2)

The newly built mobile phone network is underutilized and its energy efficiency is really bad. The best energy efficiency is achieved by using the entire network capacity, closing the network or delaying the construction (getting the real need for the network).



(3)

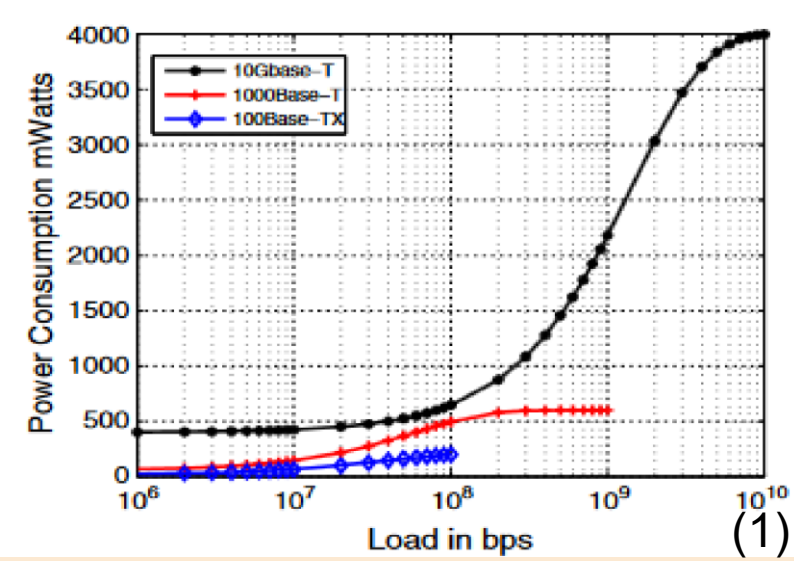


(4)

1: Elisa 2. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=10005276 3. VTT 4. Ericsson

Development of fixed network electricity consumption

- Speeds have increased, a larger amount of data is transferred with the same amount of energy.
- Suitable number of ports and modularity of devices.
- Power saving functions (in low load situations).
  - Energy Efficient Ethernet (EEE) and adaptive link speed see picture ->
  - Power-saving functions of other technologies, e.g. VDSL2



(1)

Without power-saving features, data transfer at low speed through faster ports/technologies consumes much more electricity than with slower ports/technologies, but the difference is still significant.

1: https://core.ac.uk/download/pdf/29406673.pdf

Telecommunication emission differences

Fixed network:

+ Long lifetime on the network +50 years

+ Long life cycle of devices 10-25 years

+ Low electricity consumption

- Building of the network
- Fixed (can’t take away)
- Troubleshooting and repair
- Various technologies that are not downward compatible
- Dismantling the network (ground cables)

Mobile network:

+ Mobile (can be taken with you)

+ Very comprehensive device support with 2G network (new devices downwards compatible)

+ Long life cycle with 2G +30 years

- Short life cycle with devices 4-10 years
- High power consumption
- Building of the network
- Troubleshooting and repair
- New technologies are not compatible with old devices

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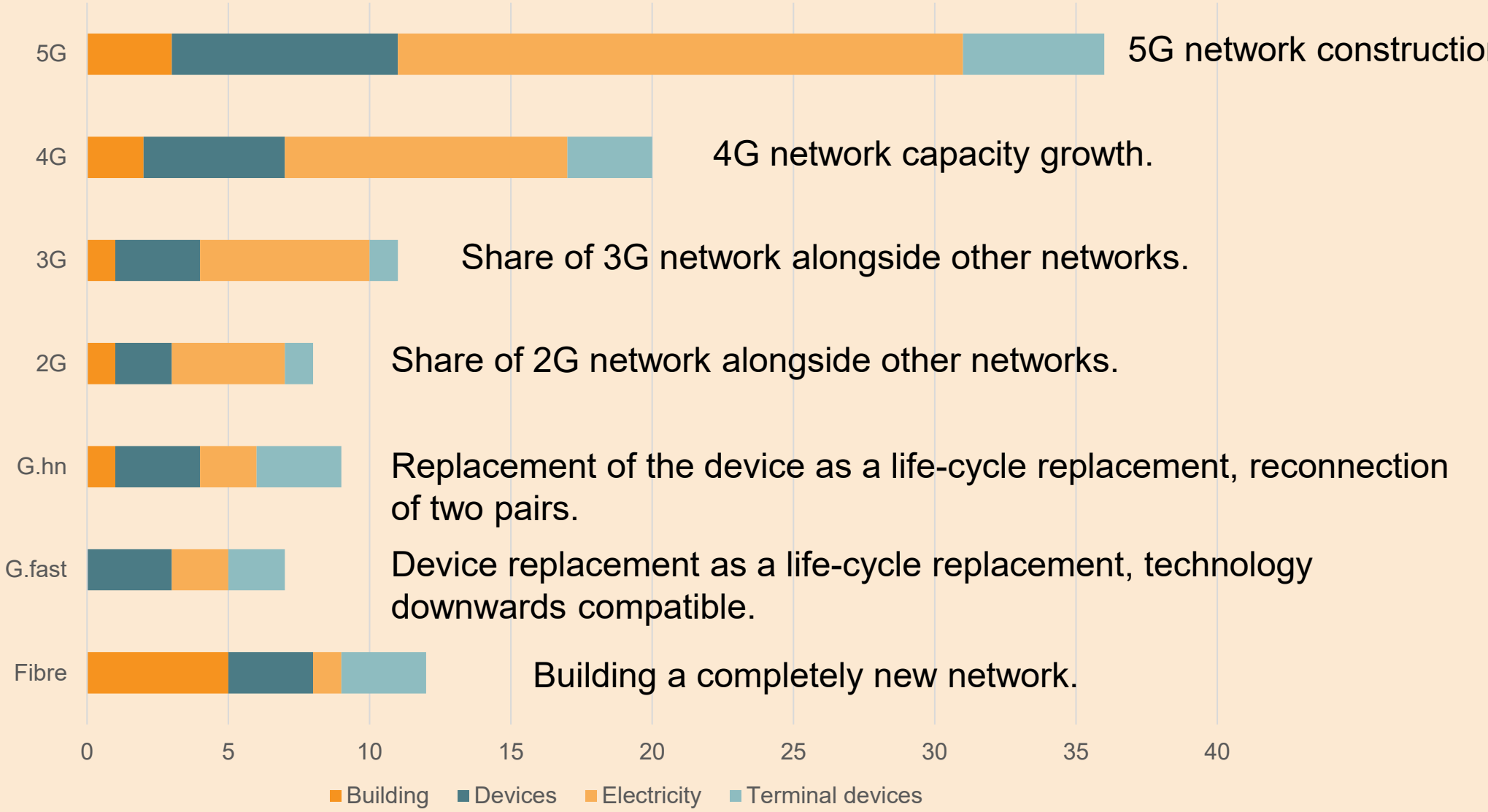
Share of telecommunications emissions in different technologies (estimate)



5G network construction.

4G network capacity growth.

Share of 3G network alongside other networks.

Share of 2G network alongside other networks.

Replacement of the device as a life-cycle replacement, reconnection of two pairs.

Device replacement as a life-cycle replacement, technology downwards compatible.

Building a completely new network.

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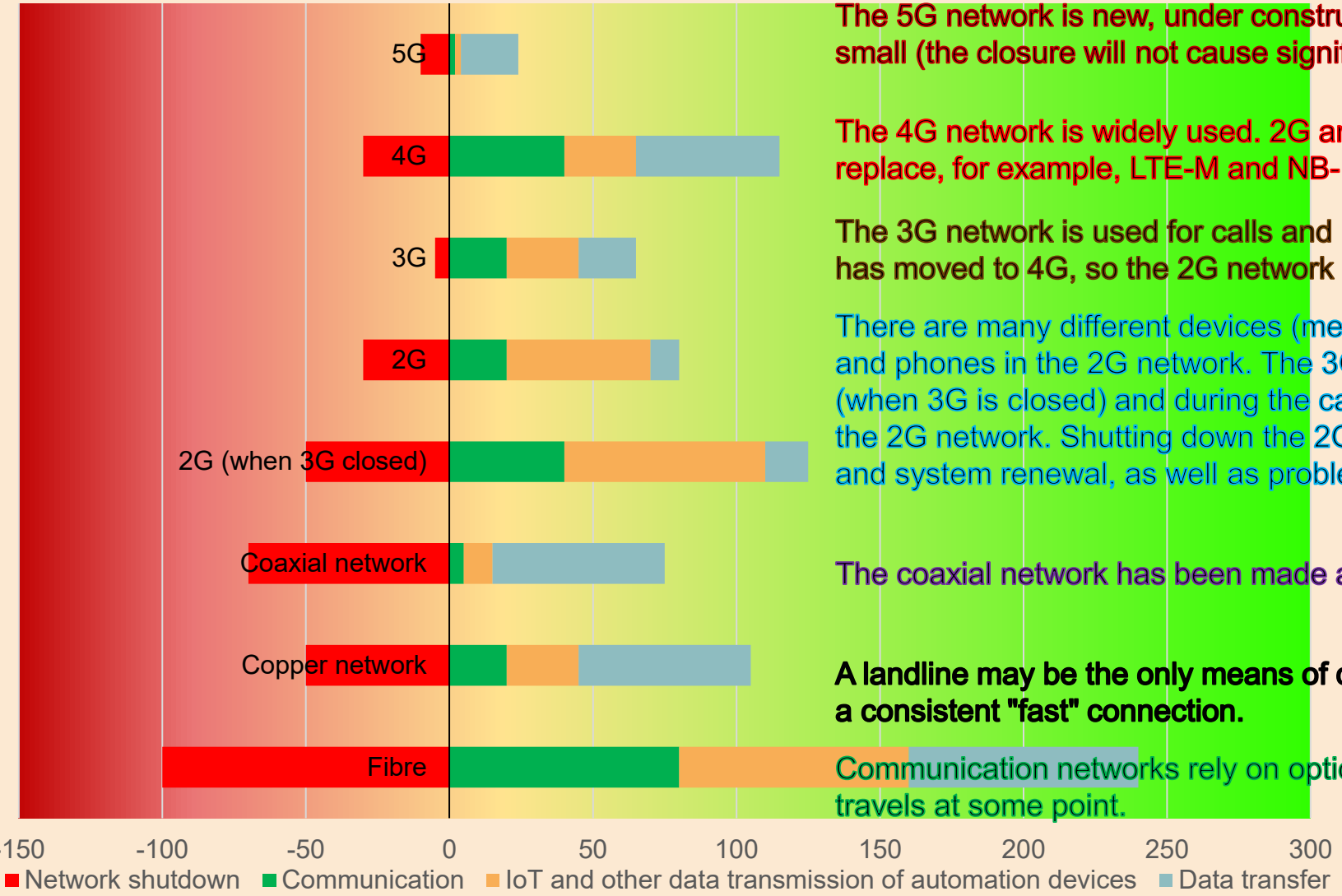
Telecommunications handprint (estimate)



The 5G network is new, under construction, and the number of devices is small (the closure will not cause significant harm yet).

The 4G network is widely used. 2G and 3G networks cannot completely replace, for example, LTE-M and NB-IoT technologies.

The 3G network is used for calls and M2M data transfer, "fast" data transfer has moved to 4G, so the 2G network is enough to replace.

There are many different devices (meters, cars, remote control devices) and phones in the 2G network. The 3G devices switch to the 2G network (when 3G is closed) and during the call some of the 4G/5G devices go to the 2G network. Shutting down the 2G network means a lot of equipment and system renewal, as well as problems with calls.

The coaxial network has been made an "alternative" to optical fiber.

A landline may be the only means of communication that works. It enables a consistent "fast" connection.

Communication networks rely on optical fiber, along which "all" traffic travels at some point.

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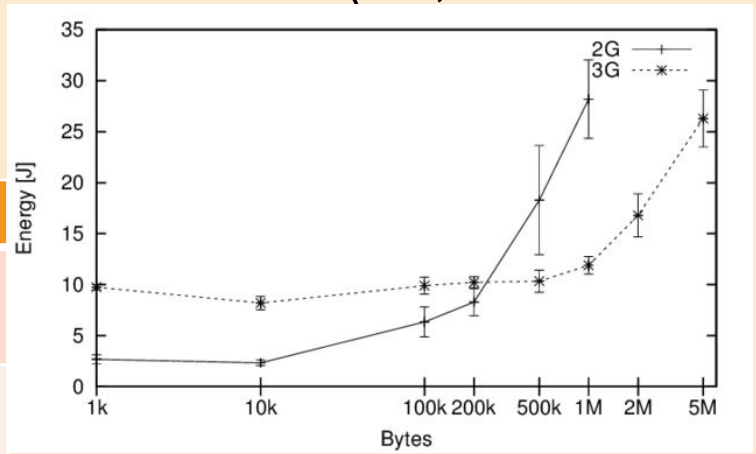
How to sustainably dispose of network components that are no longer in use?

- By leaving as a backup connection, in case of a possible crisis situation.
- By passing it on (utilization as is or for a new purpose) For example: village network, automation connections, controls and to feed devices with low power (e.g. network equipment, lighting, amplifiers, etc.) Various new applications could be power supply for fiber optic modems when the power grid fails, lighting (for garbage sheds, alleys or mailboxes) or smart mailbox.
- By donating to the museum.
- Utilization as parts or in other uses, e.g. by selling (telephone cable is suitable for e.g. IoT uses, as well as cases, cabinets, etc.).
- The last option is recycling as a material (raw material), as energy or for disposal (Waste law 8§ 646/2011).

Electricity consumption of mobile network terminal devices (e.g. smartphone)

- Mobile phone network terminals consume about 10% of electricity compared to the consumption of base stations. (1)
- The transfer of small amounts of data is more energy efficient in a slow network (2G, LTE-M ja NB-IoT). See the picture →



(1)

Mobile phone consumption (measured):

Technology	Huawei Honor 8 (4G)	Samsung Flip 5 (5G)
Data disabled IDLE 2G / 3G / 4G / 5G (NSA) mA (12,4 V)	11-14mA / 12-13mA / 13-20mA / -	12-15mA / 12mA / 12-17mA / -
Data enabled IDLE 2G / 3G / 4G / 5G (NSA) mA (12,4 V)	Not tested	19-25mA (rarely spikes) / - / 20-40mA (often spikes) / ~39mA (often spikes) (spikes: 120-300mA)
Call (listen) 2G / 3G / 4G / 5G (NSA) mA (12,4 V)	38mA / 63-65mA / - / -	48-50mA / 56mA / 42-43mA / -
Call (speaking (send)) 2G / 3G / 4G / 5G (NSA) mA (12,4 V)	~120mA / 63mA / - / -	150-160mA / 120mA / 41-50mA / -

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1: https://www.researchgate.net/publication/221545399_Software-related_energy_footprint_of_a_wireless_broadband_module

How to reduce your share of electricity consumption

- Prefer fixed connections (or a Wi-Fi connection via a fixed connection).
- Turn off terminal devices (e.g. router, modem) when you don't need them.

Fixed network:

- **Use energy efficient devices.**
- **Choose the connection speed and technology that suits your needs.**
- **Avoid cable modem if other fixed network technologies with suitable speeds are available.**

Mobile network:

- Transfer data with the best signal strength as quickly as possible.
- Choose the most suitable network generation for your needs, e.g.
  - 2G for small amounts of data (instant messages, e-mail)
  - 5G downloading large files

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