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Horizontal 6G

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Abstract—This paper describes a new architecture for 6G, the Horizontal 6G. The architecture is fully distributed and based on mobile embedded MEC (Multi-access Edge Computing) data centers. Mobile MEC nodes host all necessary processes for the life of the digital infrastructure with proximity services. This architecture is different from traditional vertical solutions by a full mobility of antennas and data centers and the use of 6G-D2D communications between edge nodes.

Index Terms: Horizontal 6G, Embedded MEC data centers, full distribution, mobile antennas, mobile data centers, direct communications, D2D.

1- Introduction

Many architectural proposals were made for the 6G going from totally centralized to fully distributed [1] to [5]. These architectures are based on vertical techniques, i.e., with fixed antennas and fixed cells. The vision of Green Communications is a total distribution of all infrastructure and service functions on a meshed network of mobile Edge machines located on or near users. Edge machines host digital services and use 6G D2D communications for transferring vicinity traffic from source to destination through the horizontal network of edge nodes. This solution is named Horizontal 6G.

An Internet network is created by interconnecting machines that integrate the TCP/IP protocol stack and servers for providing applications to the clients of the network. Machines of the Internet can be huge servers, small computers, or even smartphones. Any electronic machines equipped with a processor, memory and network interfaces can participate to an Internet Edge network. This network can connect with the global Internet with gateways or remain autonomous.

Horizontal 6G is an Internet Edge network created by the electronic machines of participants. A participating device can be a smartphone, a hotspot, a vehicle, or a drone making its resources available to achieve the network's intelligence and the services [6].

Nowadays, the global Internet provides a large number of services, but it consumes a lot of resources due to the distance between clients and servers. When a user sends a message, even to his/her immediate neighbor, the data will travel a long way to a server in a datacenter and then go back to the neighbor. This long travel of the information introduces delays, and is responsible for waste of resource. In this architecture, huge datacenters are energy intensive, and difficult to control and secure.

De-globalizing the Internet is possible using nearby resources to provide services. Like Airbnb and Uber that enable anyone to share his resource (house, car, etc.) to enrich the accommodation or transport offers, one can enhance the

Internet enabling his devices to communicate directly with neighboring users. Data shared at vicinity will stay local rather than doing a long travel over the global Internet. The user is no longer a consumer of the resources of the environment but on the contrary, he participates in the creation and the life of the digital infrastructure of this new concept of Internet.

Horizontal 6G is a new paradigm bringing together direct autonomous communications between mobile or fixed electronic machines, called nodes, and IT concepts from Edge Computing. It completes the usual Internet by using the same protocols in a distributed way and various Edge data centers. IP compatibility allows a user to connect/ disconnect from the global Internet without affecting the local network functionality. When a user disconnects, services utilizing centralized servers in the global Internet may be stopped. On the other hand, the local communications of the Horizontal 6G will remain available as the network is alive and designed by its participants.

The Horizontal 6G allows mobility, independence, autonomy, instantaneous deployment and strong security. This is ideal for businesses to manage their information systems for low latency real time applications while providing increased resiliency for their IT environment. It is also very suitable to telecommunications operators since this permits an immediate extension of their network.

The architecture of the Horizontal 6G is designed to create a new world of mobility. This can be used to create vehicular networks and it should become the standard for mobile Internet infrastructure. Numerous forecasts [7] show that car drivers will switch to an Internet connection instead of driving. As a result, the volume of data passing through the mobile Internet could reach half the volume of the Internet. The Horizontal 6G is suited to robot networks, drone networks and all networks in which humans, machines or objects are moving. This is particularly suitable for tactical bubbles and intelligent spaces.

This new Horizontal 6G paradigm is related to ad-hoc and mesh technologies in hybrid mode with the processing of data and applications being carried out on the Edge.

The remainder of the paper is structured as follows: section 2 presents the digital infrastructure of the Horizontal 6G. Section 3 deals with some Horizontal 6G key use cases. The deployment of the Horizontal 6G is presented in section 4. Section 5 presents current and future developments and some measurements realized on an advanced prototype. Finally, section 6 concludes the paper.

2- Digital infrastructure of the Horizontal 6G

The Horizontal 6G is based on a digital infrastructure which combines Edge-based IT on Edge data centers close to users, and where the Edge data centers are interconnected by a mobile,

flexible and autonomous network. Thus, a distributed Edge Cloud can be created close to the users. Users participate in this flexible infrastructure by adding their resource to it. Users can be participants in a tactical bubble, in an intelligent environment such as a smart city, or they could be the employees of a company to build the company's digital infrastructure, or individuals to create a cluster in order to share resources.

2.1- The network

The Horizontal 6G network is made of Edge data centers that form the nodes of the network. When the nodes are connected to the Internet (or any other external network), they must use a gateway. The Edge data centers integrate the protocols of the Internet but in a completely distributed way, so that the loss of one node does not change the network and its operation. The clients are connected to the nodes as shown in Figure 1.

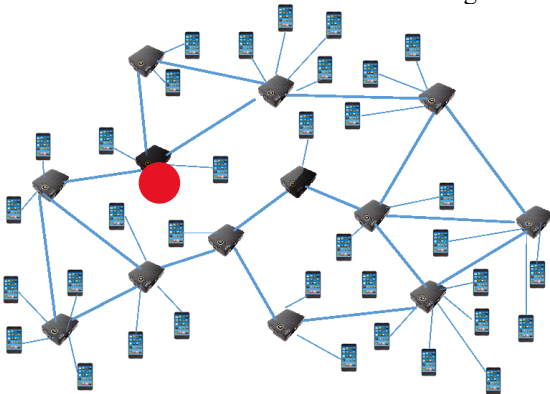


Figure 1 – A mesh network

In Figure 2, we show an example of the network after losing two nodes.

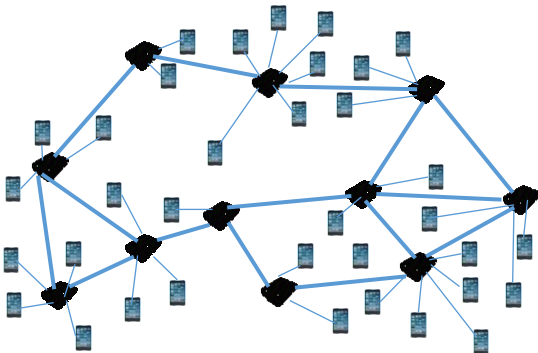


Figure 2 – The mesh network after the loss of two nodes

The technical name of these networks is mesh if the nodes are different from the user equipment and ad-hoc if they are integrated into the user equipment. The nodes interconnect with each other by autonomous direct mode connections which can use any type of technology. Of course, the most usual case comes from Wi-Fi but the connection could be achieved by a standalone 5G D2D, an IEEE 802.11s or a Bluetooth transmission or any other wireless technology adapted to a specific application. The connection can also be a fixed network like Ethernet but in this case, we lose the property of mobility. Nodes can also be connected to each other through several types of infrastructure. For example, nodes and/or terminal

equipment can be connected using a 4G or 5G infrastructure. Routing in the 4G or 5G infrastructure involves passing through an antenna or even two antennas connected to a 4G core network and soon to a 5G core network.

The nodes can use simultaneously several different D2D connections selected by an algorithm that chooses the best technology at any time. This algorithm is applied end-to-end and it selects the best path by considering the characteristics of D2D links. The best path is selected using criteria, such as, speed, energy consumption, and security.

The clients are connected to the nodes through a second interface which can be Wi-Fi, Bluetooth, or any other interface available in the nodes. Therefore, there are two interfaces per node which usually come from two Wi-Fi cards, but other solutions are possible, such as, separate Wi-Fi on different frequencies, and Wi-Fi and Halow. It is also possible to use only one Wi-Fi card to connect both nodes and clients. Of course, there can be several different interfaces in the client equipment which can be objects, machines, human users, etc.

The nodes are fixed or mobile or even be fixed at certain period of time and mobile at others. For mobile equipment, the nodes can connect and disconnect according to the neighbors. If a node is too far from its neighbors, it disconnects without modifying the operation of the network. When it gets closer to a neighbor, it instantly connects to its neighbor and, after a short delay dedicated to updating, it takes part in the processing of applications integrated into the nodes [8].

The most used function to connect two devices is defined via the maximum capacity between the devices. We show in Figure 3 some examples of connections between two clients.

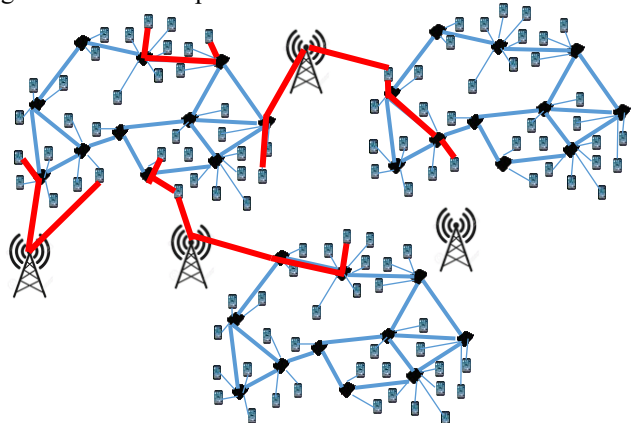


Figure 3 – Four examples of end-to-end communications

There are many algorithms that optimize the throughput between two clients. The speed of a connection between two nodes depends on the distance since the power decreases as a function of the squared distance. The solution is to route packets from node to node, without skipping intermediate nodes, so that to achieve a higher throughput. The difference can be huge, up to a 20-fold increase in flow, or even more. In Figure 4, we see that a device can reach another device through direct links with a bit rate of 1 Mbps. At the same time, the device can reach the other device without skipping intermediate nodes with a bit rate of 8 Mbit/s.

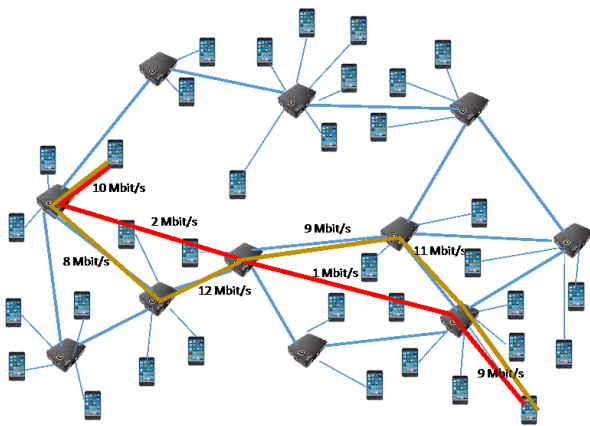


Figure 4 – End-to-end throughput

2.2- The Edge

The Horizontal 6G comes from the alliance of mesh and Edge technologies. The node is indeed an Edge data center whose objective is to process the data coming from the connected equipment. The Edge data center can use different technologies supporting virtual machines, containers or any other similar solution.

Inside a cluster, all the nodes form a local Cloud, also called an Edge Cloud. The data are stored in this Edge Cloud and all the clients connected to the cluster can access them. Virtual machines integrated into the system are available to enable the implementation of many services. These services are distributed at the edge of the network, close to the user and the data source.

One of the advantages of Edge technology is of course the latency which is extremely low, thus allowing the introduction of real-time applications. The Edge Cloud also minimizes the use of the network bandwidth by processing raw data at its source and by forwarding only processed data to remote servers. Another advantage of the Edge Cloud is that it is autonomous with regards to the Internet as vicinity data and services stay local, near the user, without using the network infrastructure. Last but not least, Edge technology achieves significant energy savings on communications by avoiding the long travel of bytes of information over the Internet and limiting the use of data center's resources.

Since in the Horizontal 6G environment, nodes can disappear, appear, or reappear, it is necessary that the system be resilient to any form of network failures or internal attacks. So, we need a fully distributed Internet environment that requires network protocols and applications fully distributed and integrated into the nodes. Any other application can be added in this open environment.

2.3 Local Services

The concept behind the Horizontal 6G is to re-localize some Cloud services at the network Edge, close to users and data sources. As a result, latency is reduced, network bandwidth is optimized, energy is saved, and more autonomy with regards to the network infrastructure is achieved.

Prominent services to be re-localized concern direct mode connection between two neighboring nodes, i.e., voice calls, instant messaging and videoconferencing.

Thanks to collaborative applications for sharing files and publishing information among users of a Horizontal 6G, a user can get information directly from the vicinity using local services such as localization, provisioning of nearby sensors, and control of camera data streams.

These applications can use native applications or web-based services.

The concept of Horizontal 6G is revolutionary in its ability to adapt to all contexts, mobility, security, and agility. This concept can be deployed or inserted anywhere in open or closed environments, fixed or mobile, or a mix of these. Its integration into the existing infrastructure is simple since there is no functionality required from the outside.

A simple way to implement a Horizontal 6G is to set it up as a closed environment, without any connection to the outside. This solution avoids all external attacks with a 100% guarantee against cyber-attacks. A gateway can be installed between a Horizontal 6G network and the outside world with a policy to open up during times determined by specific rules.

Packets circulating within the network are encrypted. Encryption is exploited even during client handovers from one node to another, which provides end-to-end security against eavesdropping.

The Horizontal 6G is designed to be agnostic to the transmission technology between nodes so that the installation of cards and drivers for specific protocols on various frequencies is simple. The network uses IP routing technique which leaves a completely open choice for layer 2.

3- Horizontal 6G key use cases

The Horizontal 6G makes it possible to mount tactical bubbles or intelligent spaces, called Internet Edge network or Internet Edge. Two completely sealed clusters can connect with each other, if necessary. Clusters can move, split and merge. They are linked together by VPNs which are considered logically as one-hop links. In Figure 5, we give a possible topology involving three clusters.

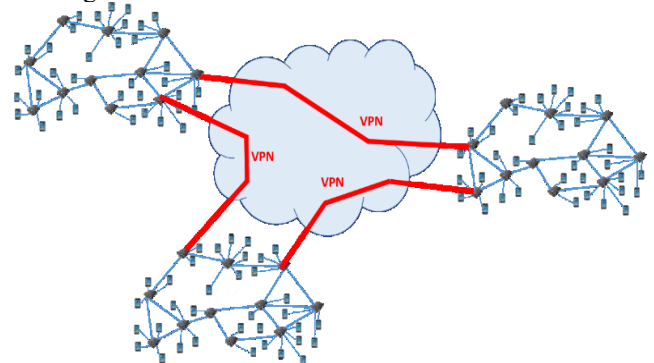


Figure 5 – A three-cluster interconnection

Horizontal 6G is also perfectly suited to networks of vehicles, drones, robots and all things that move, with sufficient node density for the radio to be able to link the nodes together, depending on the technology, most often Wi-Fi, 4G and soon 5G D2D. Using appropriate frequencies and power, the interconnection network can range from very small to very large with a range of several kilometers between nodes. The

performance obtained depends on the density of the nodes, the radio technology, and the transmission power.

Civil security and defense applications

The Horizontal 6G is perfectly suited to public safety and defense applications that require high level of resiliency, security and interoperability for providing real-time applications such as voice and video to forces while on mobility. Networks are formed from the contribution of resources available on the field (e.g. people, IoT, vehicles, drones, robots, etc.). Applications must continue to function regardless of which nodes disappear or appear in the infrastructure. The clusters may include from several tens of nodes to several hundreds of nodes. Multiple clusters can be involved.

Internet of Things

Many objects are positioned to set up smart clusters, for example, in a smart building, smart city or a smart hospital. These objects connect to nearby Edge data centers using any transmission solution available in the nodes (Wi-Fi, Bluetooth, etc.). The nodes of the cluster collect the data streams coming from the objects, analyze them locally, and feed the edge applications of the cluster. Some data may go outside the cluster to reach a central cloud or other clusters deployed at other locations such as homes for telemedicine or teleworking.

Connected and autonomous vehicles

The Horizontal 6G provides a perfect environment for vehicular networks. All the necessary ingredients are present: generalized mobility, direct communications, and Edge data centers providing local storage and computing resources. The vehicular internet is an extension of the Horizontal 6G.

Telecom applications

The Horizontal 6G forms a natural extension of the telecom operator networks. Thanks to the instantaneous nature of the Horizontal 6G, it can take over at locations without or with limited coverage (e.g. tunnels, resorts, or a space after a disaster). The Horizontal 6G can offload operator traffic when overloaded (e.g. traffic jams, large events, etc.). Interconnection with traditional telecom networks is carried out via gateways with seamless interoperability since both networks use the same IP protocol (Internet Protocol).

Industry 4.0

Industry 4.0 is a concept that provides a new production method that integrates physical machines, control software and management methods such as ERP (Enterprise Resource Planning). The structure of the Horizontal 6G applies directly to the environments of Industry 4.0. Edge data centers are fixed or mobile and can follow assembly lines or machine tools. These Edge data centers can host artificial intelligence programs and process data at the source while sharing their knowledge with nearby edge data centers instantaneously for providing an instant response to the production line. Security and resilience are intrinsically ensured by the distributed and autonomous properties of the Horizontal 6G.

4- The deployment of the Horizontal 6G

The deployment of a Horizontal 6G is almost instantaneous, the time for nearby nodes to discover each other and form a cluster.

4.1- Deployment

Deployment consists of positioning the nodes in different places and turning them on. These nodes can be either powered by an electrical source if the node is fixed, or by a battery if the node is mobile. The network is created automatically without manual intervention and becomes ready to be used as soon as all the nodes have recognized their neighbors. The time required to start the network can be in seconds.

4.2- Scalability

To scale up and create a vast horizontal 6G infrastructure, one may federate clusters operating at multiple locations. Several solutions can be used to create this set of interconnected clusters.

Autonomous clusters, which can be tactical bubbles or intelligent spaces, operating each an independent Horizontal 6G, can interoperate. Therefore, a master node is elected to represent the cluster. The election can be done using distributed consensus algorithms existing in the literature such as Paxos or RAFT. The master node can change over time for several reasons, such as, nodes' mobility, loss, damages, changes in the network topology, security, etc. Master nodes of all clusters form together a mesh network. These master nodes are linked either directly by VPNs considered as a one-hop logical link, or via 4G or 5G infrastructure connections if the two clusters are far from each other.

4.3- Energy savings

Energy expenditure is one of the important criteria in the construction of new IT environments. To that effect, the Horizontal 6G must spend the least possible energy to operate. For instance, batteries should last at least one continuous day and preferably several days.

There are two main solutions for saving energy. The first one consists in choosing energy saving components without diminishing performance and use software accelerators and optimized routing algorithms. The second solution relies on a Start & Stop technology which allows resources to be put on standby in order to reduce consumption and obtain a long battery life. Putting a node on standby is easily accomplished through a utility function. When this function is equal to 0, the node is no longer useful. This function considers the node's participation in the available paths of the network. Starting up a node is more complicated, as it has to be determined if the node has become useful again. A simple solution is to turn it on, for example, every 30 seconds, to test the usefulness of the node and then switch it off again if it is not useful [9], [10].

4.4- Security

Security against conventional attacks and cyber-attacks is intrinsic by nature of the Horizontal 6G. The network is disconnected from the Internet and operates independently on its own. If a gateway allows the passage of flows during certain time intervals, then it is the manager's responsibility to set up an adequate firewall. Eavesdropping attacks must be annihilated by encryption carried out at one end and continuing all along the routes including handovers.

A blockchain can be integrated into network nodes to ensure the certification of certain transactions, the traceability of operations, monitoring and security. The blockchain is

positioned in a closed environment and uses consensus algorithms like RAFT and Paxos. The blockchain is generally private given the applications of the Horizontal 6G. Blockchain can also be public, but the associated consensus should not consume too much energy if the nodes are mobile. Consensus techniques with proofs of work have to be avoided except when mobile nodes can be connected to significant energy sources.

4.5- The ad hoc Horizontal 6G

So far, the mesh environment and Edge data centers have been integrated into the nodes of the digital infrastructure. Another solution is to carry all the software of the Horizontal 6G in the user equipment. This provides an ad-hoc network. The benefit of an ad hoc solution is to avoid a radio connection to the client. However, the disadvantage is the need for the user to carry an additional equipment. Instead, the digital infrastructure is directly inserted in the user terminal, the Horizontal 6G being created simply by interconnecting user equipment.

In the category of ad-hoc Horizontal 6G, we can place networks of smartphones, drones, robots or even vehicles or a combination of these devices. Tests were already carried out some years ago for smartphone networks but they had not been conclusive due to the immaturity of the routing algorithms used. Nowadays, progresses in the field enable to envision a Horizontal 6G at a scale of a city with clusters made of Android or iOS smartphones, drones, robots and vehicles [11].

5- The example of Green Communications

Green Communications markets a Horizontal 5G/6G solution which incorporates all the characteristics indicated in the previous sections. The Green Communications solution is called Green PI (Participative Internet). Network nodes are called YOI (Your Own Internet) nodes.

Several tens of megabits per second have been reached over a network of 30 wireless hops using Wi-Fi 4. Wi-Fi 6 is also available increasing significantly the throughput. With current developments in the latest Wi-Fi generations (Wi-Fi 6 and Wi-Fi 6E) and the introduction of the 5G D2D being standardized by 3GPP in the document 5G-V2X mode 2, link capacity will be multiplied by a factor of more than ten compared to the use of Wi-Fi 5 or 4G in infrastructure mode.



Figure 6 – Green Communications applicative interface

The application interface is described in Figure 6. This is available on all the screens of the user equipment, whether it is a smartphone, a tablet or any other machine with a screen.

Nodes also indicate a lot of information in addition to the quality of the link, such as the vCards published by each YOI node and the neighbors connected directly to the node.

Green PI software can also be deployed as a software on customer-specific hardware with communications interfaces offering speeds associated with the technology used. Edge data centers are small with a limited capacity in the standard products commercialized by Green Communications. However, Edge data centers can be added on demand with much higher capacities.

Cartography

A connection between two nodes is indicated by a line whose thickness account for the throughput of the connection. Figure 7 gives an example of a deployed network. We also observe on this diagram the values of the signal strength on the different links.

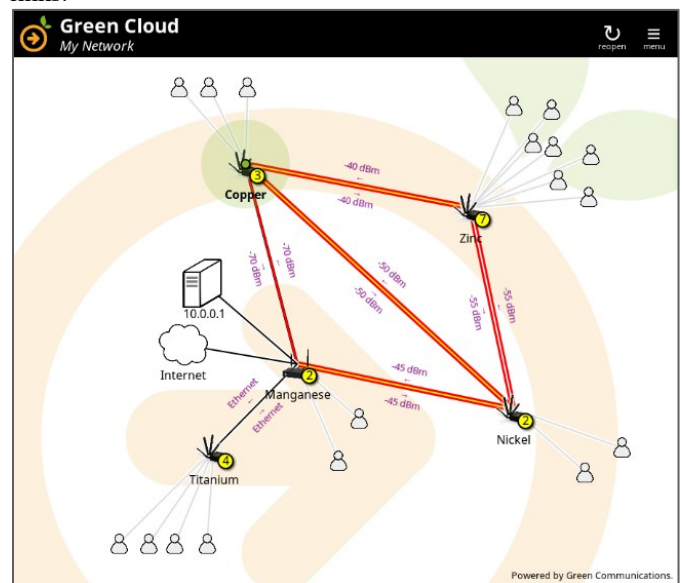


Figure 7 – An example of a Horizontal 6G deployment

6- The future

6.1. The short-term future

One can imagine many uses of the Horizontal 6G. Straightforward usages of this solution include neighbors, in ad-hoc mode, which pool sufficient resources to create a common private local cloud for data sharing. Data can be encrypted to maintain the necessary confidentiality while supporting generic applications that can be easily shared among all participating partners.

Companies can protect themselves from cyberattacks and mount highly personalized information systems. Company staff no longer have access to internet services, but only to services offered internally.

Smart vehicular networks also form a source of many relatively short-term applications that allow vehicles to simply share resources. This solution allows passengers and soon the driver to share real-time games or to work as if they were in the office.

Intelligent spaces can also be deployed using a Horizontal 6G to create the digital infrastructure and provide the computing and storage capacity that brings intelligence.

6.2. The long-term future

The long-term future of computing and networks is expressed in two very different ways by looking at the first studies on 6G which will be deployed from 2030. A rather centralized solution is pushed by telecom operators. This solution relies on SDN-type technologies with controller interconnections to scale up. In this case, 6G networks will have base stations carrying MIMO with one million antennas with the transition from the 5G massive MIMO 1024 to an ultra-massive MIMO a thousand times larger. This solution leads to an antenna per user, extended by a network per user forming a slice. To manage this excessively complex environment of antennas and slices, a control center is offered with all the necessary intelligence.

The second solution is the opposite. This solution is fully distributed as the Horizontal 6G. This solution could materialize with a restart of distributed solutions which brought the success of the Internet. The difference with the usual Internet comes from considering mobility, digital infrastructure and distributed computing in the Edge. In addition, the Internet was available to users for transport while the new generation of Horizontal 6G brings network connectivity, storage, computation, security and intelligence through the nodes of the network.

6G will perhaps materialize by setting up billions of autonomous nodes belonging to users, companies and telecommunications operators, interconnected but without any central control. This is the basic idea in the original Internet architecture that was so successful. The reasons for this fluctuation between centralization and distribution are easy to guess. We centralize when the distributed intelligence is insufficient to solve the problems and we distribute as soon as a collective intelligence can be obtained in a distributed way. The 2010s saw the arrival of intelligence but in a centralized form, the years 2025-2030 will see distributed network control again thanks to the capacity put into the Edge. The years 2020 to 2025 will form a transition from one technology to another.

7- Testbed

Green Communications has developed a large testbed to assess the performance of the solution. We have opted in using a blockchain services that has been developed on the testbed to prove the potential of the Horizontal 6G. The testbed environment is shown in Figure 8.

Green Communications' blockchain is operating on a mobile mesh network in which splits and merges may occur. This blockchain is based on the blockgraph paradigm allowing a continuity of the blockchain during split and merge operations [12] to [15].

The objective of the tests is to assess the data integrity and network capacity on a fixed and dynamic environment using the blockchain. For this, we will study the ability and consistency of the blockchain, subject to various network configurations. Among the tests, we choose to highlight two of them.

1) Fixed environment without mobility

- a. Uploading files on the blockchain with two types of radio environments (we emulate the 5G/6G direct mode D2D by a Wi-Fi 4 and Wi-Fi 6 direct mode). The goal is to measure how long does the blockchain takes to validate a new block.
- b. Downloading files in the blockchain with one hop and comparing performance between direct mode using Wi-Fi 4 and Wi-Fi 6. The goal is to see the impact of multi-hop mesh communications on the performance of the blockchain.

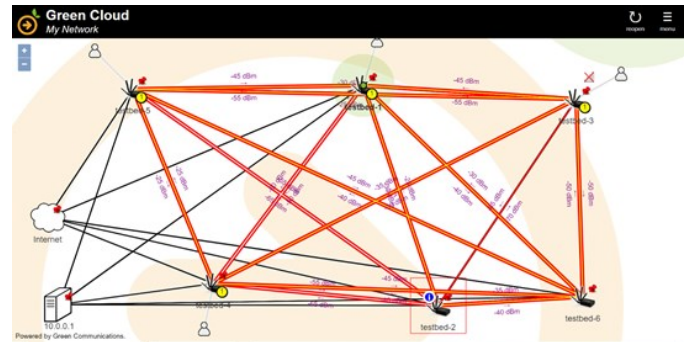


Figure 8 – The testbed used for validation

2) Mobile environment:

- a. Realization of a split achieving a partition of the testbed into two separate networks and uploading files on each partition of the network.
 - b. Realization of a merge reaching the fusion of the two partitions of the network into one partition.
- The objective of both tests is to verify the ability of the blockchain to ensure data integrity when submitted to a dynamic network environment.

The result of the tests are as follows:

Test 1) a. Fixed environment without mobility: uploading files on the blockchain with two types of radio environments (D2D emulated by a Wi-Fi 4 and a Wi-Fi 6). In this experimentation, a client connected to testbed-1 creates a directory in which it uploads multiple files of different sizes. The user reports for each file the interval of time that the blockchain takes to record the event and to validate a new block.

The results of the tests are reported in Figure 9. In this Figure, we compare the upload time of the same file on a Wi-Fi 4 and Wi-Fi 6 network and we measure the gain provided by the use of the last Wi-Fi generation on the performance of the blockchain in a network without mobility.

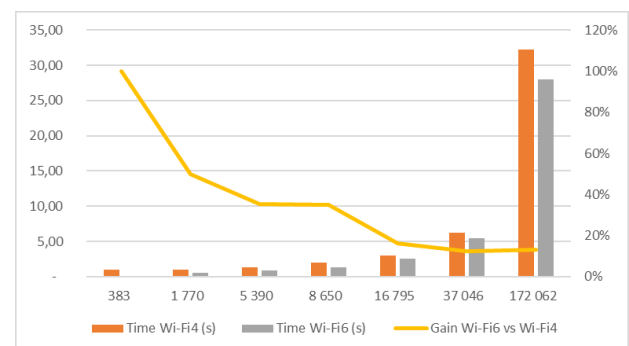


Figure 9 – Comparison of the upload time of the same file on a 5G/6G direct mode, emulated through Wi-Fi 4 and Wi-Fi 6

Figure 9 shows that the upload time of a file in the blockchain is proportional to the size. The bigger the file is, the longer it is to upload. In Wi-Fi 4, the user can upload up to 1.7 MB in less than one second. In Wi-Fi 6, the user can upload up to 5.4 MB in less than a second. Wi-Fi 6 gain compared to Wi-Fi 4 is reduced as the file size increases. On the average, Wi-Fi 6 represents a gain of 37% as part of this test.

Test 1) b. Fixed environment without mobility. The blockchain file is downloaded using a Wi-Fi 4 and Wi-Fi 6 emulation with one hop.

The test environment consists in two interconnected mesh routers each having one client. The two clients can communicate together by the only available path formed by the radio link between the two mesh routers.

The experimentation consists in uploading a file on the storage within the MEC data center of the testbed-2 router using its client and download the file on the testbed-1 client. The file, initially hosted on testbed-2 will be copied on testbed-1. At the same time the file will be made available on the testbed-1 client. The file will have done one Wi-Fi hop before being accessible by the testbed-1 client. The duplication of the file is executed by the blockchain to improve the performance. The results are shown in Figure 10.

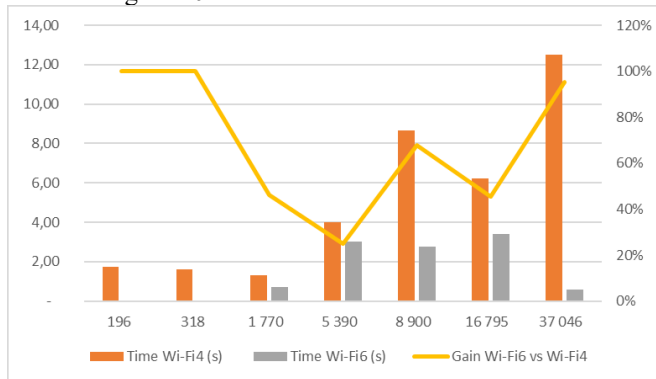


Figure 10 – Results of the measurements on the second experimentation

We observe, as well as for the live upload test, that the download time is increasing as the file size increases. The Wi-Fi 6 has better performance than Wi-Fi 4. On the other hand, the percentage of gain is variable and not decreasing as for the direct upload test (without one Wi-Fi hop).

If we compare the direct upload performance with the download for one hop, we obtain higher average performance but declining in Wi-Fi 4 (146%) against Wi-Fi 6 (73%).

8- Conclusion

Green Communications company proposes in this paper a new architecture for the 6G. This architecture considers a complete distribution with embedded MEC data centers (Multi-access Edge Computing). This architecture is different from vertical solutions by a full mobility of antennas and data centers. We have deployed this architecture by emulating 6G D2D connections by the direct mode of Wi-Fi. We also installed a blockchain on the nodes of this architecture, considering the mobility of the nodes. To validate this architecture, we

measured the performance of the blockchain with an emulation of the 6G D2D by a direct mode Wi-Fi 4 and Wi-Fi 6. All experiments have taken a very strong potential of this 6G architecture.

References

- [1] Giordani M., Polese M., Mezzavilla M., Rangan S., Zorzi M. (2020). Toward 6G networks: Use cases and technologies, *IEEE Communications Magazine* 58 (3), pp. 55–61.
- [2] Gui G., Liu M., Tang F., Kato N., Adachi F. (2020). 6G: Opening new horizons for integration of comfort, security, and intelligence, *IEEE Wireless Communications* 27 (5), pp. 126–132.
- [3] Khan L.U., Yaqoob I., Imran M., Han Z., Hong C.S. (2020). 6G wireless systems: A vision, architectural elements, and future directions, *IEEE Access* 8 (147) pp. 029–044.
- [4] Letaief K.B., Chen W., Shi Y., Zhang J., Zhang Y.-J. A. (2019). The roadmap to 6G: AI empowered wireless networks, *IEEE Communications Magazine* 57 (8), pp. 84–90.
- [5] Tariq F., Khandaker M.R., Wong K.K., Imran M.A., Bennis M., Debbah M. (2020). A speculative study on 6G, *IEEE Wireless Communications* 27 (4), pp. 118–125.
- [6] Al Agha K., Loygue P., Pujolle G.: *Edge Networking*, ISTE edition, 2022 (in French. English version to appear ISTE-Wiley).
- [7] Lv Z., Qiao L., You I. (2020). 6G-enabled network in box for internet of connected vehicles, *IEEE Transactions on Intelligent Transportation Systems*, Nov. 2020.
- [8] Martin, S., Al Agha, K., Pujolle, G.: Traffic-based topology control algorithm for energy savings in multi-hop wireless networks. *Annals of Telecommunications*, 67(3/4), 181–189, 2012.
- [9] Laubé A., Martin S., Al Agha K.: A solution to the split & merge problem for blockchain-based applications in ad hoc networks, *PEMWN 2019*, pp. 1-6, (2019).
- [10] Laubé A., Quadri D., Martin S., Al Agha K.: A Simple and Efficient Way to Save Energy in Multihop Wireless Networks with Flow Aggregation, *Journal of Computer Networks and Communications*, vol., 2019.
- [11] Shrit O., Martin S., Al Agha K., Pujolle G.: A new approach to realize drone swarm using ad-hoc network, *Med-Hoc-Net'2017*, *IEEE Xplore*, pp. 1-5, (2017).
- [12] Cordova D. C., Velloso P. B., Guerre A., Nguyen T.M.T., Pujolle G., Al Agha K., Dua G.: Blockgraph proof-of-concept, *ACM SIGCOMM Conference*, United States, pp. 82-84, 2021.
- [13] Cordova D. C., Velloso P. B., Laure A., Nguyen T.M.T., Pujolle G.: C4M: A Partition-Robust Consensus Algorithm for Blockgraph in Mesh Network, *5th Cyber Security in Networking conference (CSNet)*, *IEEE Proceeding*, pp82-89, 2021.
- [14] Cordova D. C., Laube A., Nguyen T.M.T., Pujolle G.: Blockgraph: A blockchain for mobile ad hoc networks, *4th Cyber Security in Networking Conference (CSNet)*, *IEEE Proceedings*, pp. 1-8, 2020.
- [15] Diallo E., Al Agha K., Dib O., Laubé A., Mohamed-Babou H.: Toward Scalable Blockchain for Data Management in VANETs, *AINA 2020*, pp. 33-244, 2020.