



IEEE Standard for Architecture for Low Mobility Energy Efficient Network for Affordable Broadband Access

IEEE Communications Society

Developed by the
Mobile Communication Networks Standards Committee

IEEE Std 2061™-2024

STANDARDS

IEEE Standard for Architecture for Low Mobility Energy Efficient Network for Affordable Broadband Access

Developed by the

Mobile Communication Networks Standards Committee
of the
IEEE Communications Society

Approved 6 June 2024

IEEE SA Standards Board

Abstract: Architecture for a low mobility and energy-efficient network for affordable broadband access is specified in this standard. This network is referred to as the Frugal 5G network. The network comprises of a wireless middle-mile network, an access network, and the associated control and management functions. The major interfaces in the Frugal 5G network are also specified.

Keywords: access network, Frugal 5G, IEEE 2061™, last mile connectivity, middle mile network, network function virtualization, software-defined networking

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Introduction

This introduction is not part of IEEE Std 2061-2024, IEEE Standard for Architecture for Low Mobility Energy Efficient Network for Affordable Broadband Access.

Despite the proliferation of communication networks worldwide, especially cellular networks, broadband connectivity still eludes a sizeable population globally. The lack of connectivity is a bigger problem in rural/remote areas. Moreover, even when it is available, it may not always be affordable for all, thereby restricting its usage. At the same time, communications technologies such as IEEE 802.11-based WLANs are available today, which can provide affordable broadband access. However, deploying IEEE 802.11-based WLANs in remote areas and connecting them to the Internet with the help of a cost-effective backhaul solution has its challenges. Even though affordable technologies like visible light communication or IEEE 802.22-based wireless communication technologies exist that can be used for backhauling IEEE 802.11-based WLANs, there isn't a telecommunications standard that can bring these diverse technologies together within a single architectural framework and enable the creation of an end-to-end solution to provide affordable broadband access in rural and remote areas. IEEE Std 2061™ is targeted to fill this gap. This standard specifies an architecture for a low mobility, energy-efficient communications network to provide affordable broadband connectivity in rural areas utilizing some of the existing wireless technologies, such as cellular broadband and IEEE 802.11 WLANs for access and IEEE 802.22 WRANs for backhaul connectivity.

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IEEE Standard for Architecture for Low Mobility Energy Efficient Network for Affordable Broadband Access

1. Overview

1.1 Scope

This standard specifies an architecture for a low-mobility and energy-efficient network for affordable broadband access, referred to as the Frugal 5G network. The network comprises a wireless middle-mile network, an access network, and the associated control and management functions. The architecture also specifies the major interfaces in the network.

1.2 Need for the project

Despite tremendous growth in communication technology, half of the world's population is still not connected to the Internet. The majority of these unconnected populations belong to developing countries. The situation is even worse in rural areas of these countries. The most viable method to avail broadband connectivity is via ubiquitous fiber deployment. Since a pervasive fiber network is unavailable in developing countries, the primary way to access broadband is via cellular connectivity. Cellular coverage is limited to urban/semi-urban areas, leaving the rural areas essentially unserved. It is important to note that the cellular systems are highly optimized to address the mobility challenges. This leads to an energy-inefficient network and also increases the operational cost for a network that caters to users who are either nomadic or moving at very low speeds. Hence, there is a need to design a reference architecture that can be adopted to develop a network for a low-mobility scenario and aims at providing energy-efficient and affordable broadband access for rural areas.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

⁶The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may equals is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can equals is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ETSI GS MEC 003 v3.1.1, Multi-access Edge Computing (MEC); Framework and Reference Architecture.⁸

ETSI GS NFV v1.2.1, Network Functions Virtualization (NFV): Architectural framework.

IEEE Std 802.11™-2020, IEEE Standard for Information Technology—Telecommunications and Information Exchange between Systems—Local and Metropolitan Area Networks—Specific Requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.^{9,10}

IETF RFC 7426, Software-Defined Networking (SDN): Layers and Architecture Terminology.¹¹

ONF TR-521, SDN Architecture.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹²

logical port: Denotes a forwarding interface on a software-defined switch (logical/virtual switch).

3.2 Acronyms and abbreviations

AN	access network
AP	access point
BS	base station
CN	core network
DHCP	dynamic host configuration protocol
DRB	data radio bearer
DSL	digital subscriber line

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¹²*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

DTMC	discrete-time Markov chain
GEO	geostationary earth orbit
GLSD	geo-location spectrum database
GPRS	general packet radio service
GTP	GPRS tunneling protocol
ICT	information and communication technology
IN	intermediate node
IoT	internet of things
IP	internet protocol
LEO	low earth orbit
LOS	line of sight
MAC	medium access control
MCS	modulation coding scheme
MEO	medium earth orbit
MLMF	mobility and load management function
MMN	middle mile network
MRN	multi-RAT network
NAS	non-access stratum
NFV	network function virtualization
NG	next generation
NGAP	next generation application protocol
NR	new radio
PCRF	policy and charging rule function
PoP	point of presence
QoS	quality of service
RACF	RAT agnostic control function
RAN	radio access network
RAT	radio access technology
RB	resource block
RRC	radio resource control
RSCF	RAT-specific control function
SDN	software-defined networking
SMF	slice management function
SNR	signal-to-noise ratio
SRB	signaling radio bearer
TBS	transmitted block size

TCP	transmission control protocol
UDF	user data function
UDP	user datagram protocol
UE	user equipment
UHF	ultra-high frequency
VHF	very high frequency
VoIP	voice over internet protocol
WLAN	wireless local area network

4. Notations used in IEEE Std 2061™-2024

Table 1 provides notations used in the figures shown in this standard.

Table 1—Notations used in the figures in this standard

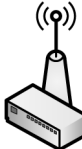
Name of the notation	Symbol
End user	
WLAN access point	
Base station	
Control signals	
Data signals	————
Control and data signals	————
Middle mile network signal	— — — — .
WLAN signal	- - - - -
Macro base station signal	
Fiber backbone	————
Population cluster	
Cloud	

Table continues



Documents
Document Sharing Hub

Table 1—Notations used in the figures in this standard (continued)

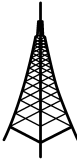
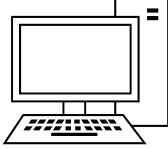
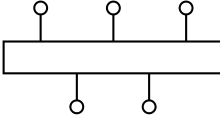
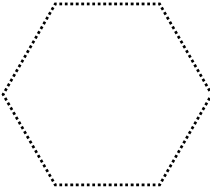
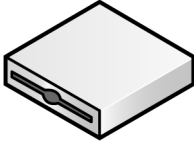
Name of the notation	Symbol
Mobile phone	
Middle mile client	
Smart phone	
Laptop	
Personal computer	
Ethernet	
Cell coverage area	
Gateway	

Table continues

Table 1—Notations used in the figures in this standard (continued)

Name of the notation	Symbol
Server	
Communications port	
Logical port	

5. Use cases

5.1 General

This clause contains the use cases that drive the requirements and architecture for the Frugal 5G network. The use cases can be categorized into the following classes:

- a) Basic connectivity-related use cases: Connectivity to information and communication infrastructure
- b) Use cases on economic opportunities, which can be categorized further as follows:
 - 1) Improvement in the financial condition of individuals/families
 - 2) Improved productivity, e.g., agriculture productivity
 - 3) Enhanced financial opportunities for small businesses/entrepreneurs in rural areas
 - 4) Support for financial inclusion: Provide access to financial products, e.g., savings, insurance, credit
- c) Use cases on human resource development or improved access to life-enhancing services, which can further be categorized as follows:
 - 1) Healthcare
 - 2) Education
 - 3) Entertainment
 - 4) Safe water, sanitation, and clean energy
 - 5) Dissemination of information to communities in disaster-prone areas to reduce the impact of disasters on communities
- d) Online access to e-governance and citizen services

5.2 Use cases on basic connectivity to information and communication technology (ICT) infrastructure

Frugal 5G network can facilitate basic connectivity between people. It can enable connectivity through services, such as voice/video calls. The network can also facilitate access to the Internet and other similar data networks, which may even be hosted at the edge near the users. The access to basic connectivity includes support for disseminating information to communities in disaster-prone areas to reduce losses in

case of disasters. Rural areas are typically populated in clusters that are generally far apart, with vast open areas in between. Many of these areas are remote and not easily accessible. Frugal 5G network can provide connectivity services to people in such areas.

It has been observed that the average income of people living in rural areas is much less than that in urban areas. This income disparity is worse in developing countries. Therefore, a large fraction of the people expected to benefit from the services of the Frugal 5G network would be people with low incomes. The Frugal 5G network will be able to cater to and serve (connect) such people, i.e., people in low-income groups.

Frugal 5G network serves mobile users by providing broadband connectivity to them. As it might be the only means of broadband connectivity to people in rural areas, supporting mobile users is an important use case for the Frugal 5G networks. However, people in rural areas, especially in developing countries such as African, Asian, or Latin American countries, typically do not use very high-speed vehicles and move at lower speeds, typically lower than 50 km/h. In such a scenario, supporting high-speed mobility (up to 500 km/h) is not relevant for Frugal 5G network, and support for only low-speed mobility (less than 50 km/h) is required.

5.2.1 Use cases pertaining to economic opportunities

5.2.1.1 Support to agriculture

5.2.1.1.1 General

A frugal 5G network can support farmers (in rural areas) by providing them with better access to the market and helping them improve their productivity. The agriculture sector faces the following issues in most parts of the world:

- Poor access to the relevant information, e.g., location of markets, supplies
- Usage of inefficient techniques for agriculture production, waste reduction, etc.
- Lack of access to finance for investment in better seeds, irrigation facilities, and other inputs
- More time/travel/money required to buy/sell and receive payments for crops
- Lack of education in farmers, for example, farmers do not have information about agricultural institutes/organizations that can provide them guidance/tips

Frugal 5G network can help address the above-mentioned issues through support for requirements identified in [5.3.1.2](#) and [5.3.1.3](#).

5.2.1.2 Improved access to market via connectivity to Internet/other networks

Access to new customers: Frugal 5G network helps farmers search for/connect with new customers/buyers online for their agricultural produce, livestock, cattle produce, etc.

Access to new suppliers: Frugal 5G network helps farmers search online for/connect to suppliers and sources of raw materials, such as seeds, fertilizers, pesticides, and farm equipment.

Support for online trade: Frugal 5G networks help farmers sell their agricultural produce, livestock, etc., and buy supplies online.

Time to market: Frugal 5G network can help farmers identify better timing to sell their produce by making relevant online information available. For example, it can help them identify suitable warehouse options for preserving agricultural products so that they can benefit from better pricing at a later stage.

5.2.1.3 Productivity improvement

5.2.1.3.1 General

Frugal 5G network can also help farmers improve their productivity. Productivity improvement can be enabled through the mechanisms outlined in 5.2.1.3.2 and 5.2.1.3.3.

5.2.1.3.2 Online information storage and dissemination

The Frugal 5G network can be used to provide farmers with online input on using the latest agricultural technology and more efficient agricultural techniques/methods. This can help the farmers be more productive and increase their income.

The Frugal 5G network can facilitate the creation of, and provide access to, personalized agriculture and livestock-related databases for individual farmers. Such databases can be created by public/private agencies to support individual farmers.

Sophisticated personalized agricultural advisories can be provided to the farmers with the help of the personalized database and through the broadband connectivity provided by the Frugal 5G network.

Such advisories can be as follows:

- Based on the farm and the farmer profile parameters, such as “crop history,” “soil health,” “pest-related information,” “irrigation needs,” etc.
- For different domains: agriculture, animal husbandry/livestock, and fisheries
- Provided by agricultural scientists/experts
- For weather conditions, for example, early-warning messages can reduce the negative impact on agriculture caused by heavy rain, etc.
- For the appropriate cultivation techniques
- For waste management techniques
- For market-related information: product (agricultural produce, livestock) prices, new customers, more affordable supplies (seeds, fertilizers, farm equipment), and agricultural byproducts

For agri-epidemics, for example, to reduce widespread insect infestation on crops. These advisories are particularly important for smallholders, and the information shall be disseminated in a way that the farmers can understand. The farmers can use the information to conserve resources, boost farmland yields, and enhance their income.

5.2.1.3.3 Digitization of agribusiness

With the help of the Frugal 5G network, farmers can use advanced technology, such as the Internet of Things (IoT), to improve the productivity of farming. The data gathered by equipment, machines, and sensors, such as soil moisture sensor feeds, can be used to support advanced agricultural techniques such as “prescription farming” to improve productivity. An example of such an application is “aquaculture health monitoring” in the UK (UK); farmed salmon is one of the largest food exports of the UK, and therefore, measuring and maintaining the parameter values (such as pH, dissolved oxygen, salinity, temperature) in and around the salmon farms is quite important. Large variations in the measured parameter values can pose serious challenges to the health of the fish and reduce the farmers’ income considerably.

Similarly, digitization of procurement of crops/livestock/supplies, digitization of waste management, digitization of farmer identity/records to support tractability and certification requirements, and usage of

mobile-enabled services to share information and support each other is also required to improve farmers' productivity and income.

Key communication/storage-related characteristics/requirements of the agriculture-related use cases are as follows:

- The need for moderate to large data transfer: lack of education may require audio/visual messages, smartphones/computers, and user-friendly apps for this purpose
- Communication and storage security: mainly not required except for financial matters
- Local storage of content near the users possible
- Typically, non-real-time communication

5.2.2 Support for small business

The Frugal 5G network can help small businesses by connecting them to the Internet. It can enable businesses to buy/sell products online. The Frugal 5G network can also provide connectivity to storage in the edge/cloud, where they can keep data/applications pertaining to their businesses. Such small businesses include hotels, shops, restaurants, etc.

This use case includes the following scenarios:

- a) Online information sharing about products/business: online publicity of deals/products
- b) Online buy/sell leading to increased business opportunities/business
- c) Storage/access of data in the edge/cloud
- d) Online/mobile payment

Key communication-related characteristics/requirements of the use case are as follows:

- Moderate level of data transfer
- Secure communication and storage
- Usage of smartphones/computers and user-friendly apps
- Secure local storage of content (in the network edge)

5.2.3 Support for financial inclusion (access to finance)

The use case should enable access to the financial system from remote/rural areas and serve people who are traditionally underserved by the financial system. This is an important requirement for farmers or other people running small businesses in rural areas. The services that this use case can enable are as follows:

- a) Enables access to banking
- b) Enables access to other financial services, e.g., access to loans, insurance, financial advisory

The use case has the following communication-specific characteristics/attributes:

- Small amounts of data transfer
- Secure communication

- Real-time communication
- Usage of user-friendly smartphone apps

5.3 Use cases pertaining to human resource development and access to life-enhancing services

5.3.1 Support for healthcare

5.3.1.1 General

The Frugal 5G network can support healthcare initiatives in rural areas. A few healthcare initiatives are detailed in [5.3.1.2](#) and [5.3.1.3](#).

5.3.1.2 Digitization of healthcare

By providing connection to the Internet, the Frugal 5G network can strengthen the collection of health-related data for remote and rural populations through online means. The data can be stored for future access, processing, and intervention toward improving the health of the rural population. This can help significantly in providing better healthcare to the rural population, especially in developing countries. The scenarios that may need to be supported are as follows:

- Collection of healthcare data from a geographical area/population
- Dissemination of healthcare-related information after data analysis and identification of healthcare needs
- Preventive healthcare information
- Information about hospitals/doctors/experts/drug availability
- Tailored information to a patient before/during/after hospital treatment for a particular disease
- Storage/access of healthcare records in the cloud

5.3.1.3 Support for telemedicine

By connecting to the Internet, Frugal 5G networks support telemedicine in remote areas, where highly qualified doctors and experts are not physically available. Connecting to the Internet via the Frugal 5G network, sharing medical reports securely, and making video and voice calls with and between experts can reduce the cost of treatment.

Patients using telemedicine can save time and costs that would otherwise be spent/lost due to travel and lost wages.

Key communication/storage-related characteristics/requirements of the healthcare use case are as follows:

- Need for huge data transfer
- Secure communication and storage
- Needs smartphones/computers and user-friendly apps
- Some local storage of content near the users possible
- Typically, real-time or soft real-time communication

5.3.2 Support for education

Internet access has become an integral part of educational activities. Due to the lack of affordable broadband connectivity, many people in rural areas without Internet service have difficulty accessing what have become basic educational activities. Without Internet access, it is more difficult to complete homework and assignments, study for exams, apply for universities, and many other education-related tasks that assume Internet access. By providing access to the Internet, the Frugal 5G network can enable students to access online resources. Apart from access to the Internet, it can also help support access to online resources, which are stored in the edge/cloud near the users.

Examples of educational services that assume Internet access are as follows:

- a) Access to e-books, e-library, online reference/reading material, and online courses
- b) Online collaboration to do the homework and assignments
- c) E-school

Key ICT-related characteristics/requirements of the use case are as follows:

- Huge data transfer may need to be done
- Communication and storage security requirements are not very important
- Needs smartphones/computers and user-friendly apps
- Local storage of content near the users
- Typically, non-real-time communication

5.3.3 Support for entertainment

The Frugal 5G network can facilitate access to online entertainment services. For example, it can enable access to articles, news, blogs, opinions, etc. so that people can read and keep themselves abreast of the latest developments. It also enables people to watch multimedia products, e.g., streaming video and accessing them from multimedia sites; such multimedia products can be stored and accessed in the local cloud (on the edge) as well. It can also provide access to online games and social networks.

Key ICT-related characteristics/requirements of this use case are as follows:

- Huge data transfer may need to be done
- Communication and storage security requirements are not very important
- Needs smartphones/computers and user-friendly apps
- Local storage of content near the users
- Typically, soft-real time communication

5.3.4 Support for access to safe water, sanitation, and clean energy

The Frugal 5G network can facilitate access to some of the basic needs of people living in rural areas, e.g., safe water, sanitation, and clean energy. Mobile apps, technologies such as IoT, and online connectivity to government offices can facilitate people's access to these basic services. Whenever people face issues accessing these services, they can raise the issues with the relevant authorities/agencies with the help of the Frugal 5G network.

Key ICT-related characteristics/requirements of the use case are as follows:

- Small/moderate data transfer may need to be done
- Communication and storage security requirements are not important
- Needs smartphones/computers and user-friendly apps
- Typically, non/soft-realtime communication

5.4 Support for e-Governance and electronic delivery of citizen services

The Frugal 5G network can support the electronic delivery of various government services to citizens, e.g., online payment of utility services, legal services, access to and modification of citizen records, such as name or address changes, citizen access to information, etc. For example, in Uganda (Africa), mobile connectivity offers an excellent mechanism for citizens to interact with e-government and other online services. Payment of personal and business taxes and utility bills, such as water and electricity bills, through mobile phones is now the primary mechanism used by a large percentage of people in Uganda. Such cases can be supported by the Frugal 5G network. The following services are typically required to be supported:

- a) Tax submission and payments
- b) Bill payments, e.g., electricity bills, land bills
- c) Access to government records, e.g., land/housing records
- d) Availing of government services, e.g., electricity/cooking gas connection
- e) Digital identity
- f) Insurance/credits
- g) Secure storage of personal documents in the cloud
- h) Direct benefit transfers: payments etc.

These use cases have the following ICT-related characteristics/attributes:

- Small amount of data to be exchanged typically
- The transactions should be secure
- The personal data should be stored in a secure manner

5.5 Key features according to the various use cases

Table 2 presents the list of required key features, summarized as per the given use cases in 5.2 through 5.4.

Table 2—Key features for different use cases

Key features	Agriculture	Small business	Financial inclusion	Healthcare	Education	Entertainment	Access to safe water sanitation and clean energy	E-governance
Huge/moderate/small data transfer	Moderate/huge	Moderate	Small	Huge	Huge	Huge	Small/moderate	Small
Secure communication and storage	Required	Required	Required	Required	NA	NA	NA	Required
Local storage near the user	Required	Required	NA	Required	Required	Required	NA	NA
Real-time communication	NA	NA	Required	Required	Required	Required	Required	NA
Smart/user friendly apps	Required	Required	Required	Required	Required	Required	Required	Required

6. Unique characteristics of rural area and associated requirements

6.1 General

This clause identifies the requirements based on the unique characteristics of rural areas, which are important considerations when implementing a Frugal 5G network.

6.2 Unique characteristics of rural areas

6.2.1 General

Considering the poor broadband penetration in rural areas, especially in developing countries, it is important to understand the unique characteristics of the rural areas and the primary challenges that hinder the deployment of broadband communication networks there. In this subclause, some of these important characteristics and challenges are identified. These traits/challenges may influence the architecture and design of the broadband communication network to be deployed in rural areas.

6.2.2 Sparse population density and clustered settlements

Rural areas are populated in clusters, which are generally far apart from each other with vast open areas in between, as shown in [Figure 1](#).