Alternative Network Deployments:
Taxonomy, Characterization, Technologies, and Architectures

Abstract

   This document presents a taxonomy of a set of "Alternative Network
   Deployments" that emerged in the last decade with the aim of bringing
   Internet connectivity to people or providing a local communication
   infrastructure to serve various complementary needs and objectives.
   They employ architectures and topologies different from those of
   mainstream networks and rely on alternative governance and business
   models.

   The document also surveys the technologies deployed in these
   networks, and their differing architectural characteristics,
   including a set of definitions and shared properties.

   The classification considers models such as Community Networks,
   Wireless Internet Service Providers (WISPs), networks owned by
   individuals but leased out to network operators who use them as a
   low-cost medium to reach the underserved population, networks that
   provide connectivity by sharing wireless resources of the users, and
   rural utility cooperatives.

Status of This Memo

   This document is not an Internet Standards Track specification; it is
   published for informational purposes.

   This document is a product of the Internet Research Task Force
   (IRTF). The IRTF publishes the results of Internet-related research
   and development activities. These results might not be suitable for
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   to the Internet for All Research Group of the Internet Research Task
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   a candidate for any level of Internet Standard; see Section 2 of RFC
   7841.

   Information about the current status of this document, any errata,
   and how to provide feedback on it may be obtained at
   http://www.rfc-editor.org/info/rfc7962.

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1. Introduction

   One of the aims of the Global Access to the Internet for All (GAIA)
   IRTF Research Group is "to document and share deployment experiences
   and research results to the wider community through scholarly
   publications, white papers, Informational and Experimental RFCs,
   etc." [GAIA]. In line with this objective, this document proposes a
   classification of "Alternative Network Deployments". This term
   includes a set of network access models that have emerged in the last
   decade with the aim of providing Internet connections, following
   topological, architectural, governance, and business models that
   differ from the so-called "mainstream" ones, where a company deploys
   the infrastructure connecting the users, who pay a subscription fee
   to be connected and make use of it.

   Several initiatives throughout the world have built these large-scale
   networks, using predominantly wireless technologies (including long
   distance links) due to the reduced cost of using unlicensed spectrum.
   Wired technologies such as fiber are also used in some of these
   networks.

   The classification considers several types of alternate deployments:
   Community Networks are self-organized networks wholly owned by the
   community; networks acting as Wireless Internet Service Providers
   (WISPs); networks owned by individuals but leased out to network
   operators who use such networks as a low-cost medium to reach the
   underserved population; networks that provide connectivity by sharing
   wireless resources of the users; and finally there are some rural
   utility cooperatives also connecting their members to the Internet.

   The emergence of these networks has been motivated by a variety of
   factors such as the lack of wired and cellular infrastructures in
   rural/remote areas [Pietrosemoli]. In some cases, Alternative
   Networks may provide more localized communication services as well as
   Internet backhaul support through peering agreements with mainstream
   network operators. In other cases, they are built as a complement or
   an alternative to commercial Internet access provided by mainstream
   network operators.

   The present document is intended to provide a broad overview of
   initiatives, technologies, and approaches employed in these networks,
   including some real examples. References describing each kind of
   network are also provided.

1.1. Mainstream Networks

In this document, we will use the term "mainstream networks" to
denote those networks sharing these characteristics:

o Regarding scale, they are usually large networks spanning entire
   regions.

o Top-down control of the network and centralized approach.

o They require a substantial investment in infrastructure.

o Users in mainstream networks do not participate in the network
   design, deployment, operation, governance, and maintenance.

o Ownership of the network is never vested in the users themselves.

1.2. Alternative Networks

The term "Alternative Network" proposed in this document refers to
the networks that do not share the characteristics of "mainstream
network deployments". Therefore, they may share some of the
following characteristics:

o Relatively small scale (i.e., not spanning entire regions).

o Administration may not follow a centralized approach.

o They may require a reduced investment in infrastructure, which may
   be shared by the users and commercial and non-commercial entities.

o Users in Alternative Networks may participate in the network
   design, deployment, operation, and maintenance.

o Ownership of the network is often vested in the users.

2. Terms Used in This Document

Considering the role that the Internet currently plays in everyday
life, this document touches on complex social, political, and
economic issues. Some of the concepts and terminology used have been
the subject of study of various disciplines outside the field of
networking and are responsible for long debates whose resolution is
out of the scope of this document.

   o "Global north" and "global south". Although there is no consensus
      on the terms to be used when talking about the different
      development level of countries, we will employ the term "global
      south" to refer to nations with a relatively lower standard of
      living. This distinction is normally intended to reflect basic
      economic country conditions. In common practice, Japan in Asia,
      Canada and the United States in northern America, Australia and
      New Zealand in Oceania, and Europe are considered "developed"
      regions or areas [UN], so we will employ the term "global north"
      when talking about them.

   o The "Digital Divide". The following dimensions are considered to
      be meaningful when measuring the digital development state of a
      country: infrastructures (availability and affordability), the
      Information and Communications Technology (ICT) sector (human
      capital and technological industry), digital literacy, legal and
      regulatory framework, and content and services. A lack of digital
      development in one or more of these dimensions is what has been
      referred as the "Digital Divide" [Norris]. It should be noted
      that this "Divide" is not only present between different countries
      but between zones of the same country, despite its degree of
      development.

   o "Urban" and "rural" zones. There is no single definition of
      "rural" or "urban", as each country and various international
      organizations define these terms differently, mainly based on the
      number of inhabitants, the population density, and the distance
      between houses [UNStats]. For networking purposes, the primary
      distinction is likely the average distance between customers,
      typically measured by population density, as well as the distance
      to the nearest Internet point-of-presence, i.e., the distance to
      be covered by "middle mile" or backhaul connectivity. Some
      regions with low average population density may cluster almost all
      inhabitants into a small number of relatively dense small towns,
      for example, while residents may be dispersed more evenly in
      others.

   o Demand. In economics, it describes a consumer's desire and
      willingness to pay a price for a specific good or service.

   o Provision is the act of making an asset available for sale. In
      this document, we will mainly use it as the act of making a
      network service available to the inhabitants of a zone.

   o Underserved area. Area in which the telecommunication market
      permanently fails to provide the information and communications
      services demanded by the population.

o Free, open, and neutral networks. Their principles have been
   summarized this way [Baig]:

   * You have the freedom to use the network for any purpose as long
      as you do not harm the operation of the network itself, the
      rights of other users, or the principles of neutrality that
      allow contents and services to flow without deliberate
      interference.

   * You have the right to understand the network, to know its
      components, and to spread knowledge of its mechanisms and
      principles.

   * You have the right to offer services and content to the network
      on your own terms.

   * You have the right to join the network, and the responsibility
      to extend this set of rights to anyone according to these same
      terms.

3. Scenarios Where Alternative Networks Are Deployed

   Different studies have reported that as much as 60% of the people on
   the planet do not have Internet connectivity [Sprague]
   [InternetStats]. In addition, those unconnected are unevenly
   distributed: only 31% of the population in "global south" countries
   had access in 2014, against 80% in "global north" countries
   [WorldBank2016]. This is one of the reasons behind the inclusion of
   the objective to "significantly increase access to information and
   communications technology and strive to provide universal and
   affordable access to the Internet in least developed countries by
   2020," as one of the targets in the Sustainable Development Goals
   (SDGs) [SDG], considered as a part of "Goal 9. Build resilient
   infrastructure, promote inclusive and sustainable industrialization
   and foster innovation."

   For the purpose of this document, a distinction between "global
   north" and "global south" zones is made, highlighting the factors
   related to ICT, which can be quantified in terms of:

   o The availability of both national and international bandwidth, as
      well as equipment.

   o The difficulty in paying for the services and the devices required
      to access the ICTs.

   o The instability and/or lack of power supply.

o The scarcity of qualified staff.

o The existence of a policy and regulatory framework that hinders
   the development of these models in favor of state monopolies or
   incumbents.

In this context, the World Summit of the Information Society [WSIS]
aimed at achieving "a people-centred, inclusive and development-
oriented Information Society, where everyone can create, access,
utilize and share information and knowledge. Therefore, enabling
individuals, communities and people to achieve their full potential
in promoting their sustainable development and improving their
quality of life". It also called upon "governments, private sector,
civil society and international organizations" to actively engage to
work towards the bridging of the digital divide.

Some Alternative Networks have been deployed in underserved areas,
where citizens may be compelled to take a more active part in the
design and implementation of ICT solutions. However, Alternative
Networks (e.g., [Baig]) are also present in some "global north"
countries, being built as an alternative to commercial ones managed
by mainstream network operators.

The consolidation of a number of mature Alternative Networks (e.g.,
Community Networks) sets a precedent for civil society members to
become more active in the search for alternatives to provide
themselves with affordable access. Furthermore, Alternative Networks
could contribute to bridge the digital divide by increasing human
capital and promoting the creation of localized content and services.

3.1. Urban vs. Rural Areas

The differences presented in the previous section are not only
present between countries, but within them too. This is especially
the case for rural inhabitants, who represent approximately 55% of
the world's population [IFAD2011], with 78% of them in "global south"
countries [ITU2011]. According to the World Bank, adoption gaps
"between rural and urban populations are falling for mobile phones
but increasing for the internet" [WorldBank2016].

Although it is impossible to generalize among them, there exist some
common features in rural areas that have prevented incumbent
operators from providing access and that, at the same time, challenge
the deployment of alternative infrastructures [Brewer] [Nungu]
[Simo_c]. For example, a high network latency was reported in
[Johnson_b], which could be in the order of seconds during some
hours.

These challenges include:

o Low per capita income, as the local economy is mainly based on
   subsistence agriculture, farming, and fishing.

o Scarcity or absence of basic infrastructures, such as electricity,
   water, and access roads.

o Low population density and distance (spatial or effective) between
   population clusters.

o Underdeveloped social services, such as healthcare and education.

o Lack of adequately educated and trained technicians, and high
   potential for those (few) trained to leave the community
   incentivized by better opportunities, higher salaries, or the
   possibility of starting their own companies [McMahon].

o High cost of Internet access [Mathee].

o Harsh environments leading to failure in electronic communication
   devices [Johnson_a], which reduces the reliability of the network.

Some of these factors challenge the stability of Alternative Networks
and the services they provide: scarcity of spectrum, scale, and
heterogeneity of devices. However, the proliferation of Alternative
Networks [Baig] together with the raising of low-cost, low-
consumption, low-complexity off-the-shelf wireless devices have
allowed and simplified the deployment and maintenance of alternative
infrastructures in rural areas.

3.2. Topology Patterns Followed by Alternative Networks

Alternative Networks, considered self-managed and self-sustained,
follow different topology patterns [Vega_a]. Generally, these
networks grow spontaneously and organically, that is, the network
grows without specific planning and deployment strategy and the
routing core of the network tends to fit a power law distribution.
Moreover, these networks are composed of a high number of
heterogeneous devices with the common objective of freely connecting
and increasing the network coverage and the reliability. Although
these characteristics increase the entropy (e.g., by increasing the
number of routing protocols), they have resulted in an inexpensive
solution to effectively increase the network size. One such example
is Guifi.net [Vega_a], which has had an exponential growth rate in
the number of operating nodes during the last decade.

Regularly, rural areas in these networks are connected through long-distance links and/or wireless mesh networks, which in turn convey the Internet connection to relevant organizations or institutions. In contrast, in urban areas, users tend to share and require mobile access. Since these areas are also likely to be covered by commercial ISPs, the provision of wireless access by virtual operators like [Fon] may constitute a way to extend the user capacity to the network. Other proposals like "Virtual Public Networks" [Sathiaseelan_a] can also extend the service.

4. Classification Criteria

The classification of Alternative Network Deployments, presented in this document, is based on the following criteria:

4.1. Entity behind the Network

The entity (or entities) or individuals behind an Alternative Network can be:

o A community of users.

o A public stakeholder.

o A private company.

o Supporters of a crowdshared approach.

o A community that already owns the infrastructure and shares it with an operator, who, in turn, may also use it for backhauling purposes.

o A research or academic entity.

The above actors may play different roles in the design, financing, deployment, governance, and promotion of an Alternative Network. For example, each of the members of a Community Network maintains the ownership over the equipment they have contributed, whereas in others there is a single entity, e.g., a private company who owns the equipment, or at least a part of it.

4.2. Purpose

Alternative Networks can be classified according to their purpose and the benefits they bring compared to mainstream solutions, regarding economic, technological, social, or political objectives. These benefits could be enjoyed mostly by the actors involved (e.g., lowering costs or gaining technical expertise) or by the local

community (e.g., Internet access in underserved areas) or by the
society as a whole (e.g., network neutrality).

The benefits provided by Alternative Networks include, but are not
limited to:

o Extending coverage to underserved areas (users and communities).

o Providing affordable Internet access for all.

o Reducing initial capital expenditures (for the network and the end
   user, or both).

o Providing additional sources of capital (beyond the traditional
   carrier-based financing).

o Reducing ongoing operational costs (such as backhaul or network
   administration).

o Leveraging expertise and having a place for experimentation and
   teaching.

o Reducing hurdles to adoption (e.g., digital literacy, literacy in
   general, and relevance).

o Providing an alternative service in case of natural disasters and
   other extreme situations.

o Community building, social cohesion, and quality of life
   improvement.

o Experimentation with alternative governance and ownership models
   for treating network infrastructures as a commons.

o Raising awareness of political debates around issues like network
   neutrality, knowledge sharing, access to resources, and more.

Note that the different purposes of Alternative Networks can be more
or less explicitly stated and they could also evolve over time based
on the internal dynamics and external events. For example, the Red
Hook WIFI network in Brooklyn [Redhook] started as a Community
Network focusing more on local applications and community building
[TidePools], but it became widely known when it played a key role as
an alternative service available during the Sandy storm [Tech]
[NYTimes].

Moreover, especially for those networks with more open and horizontal governance models, the underlying motivations of those involved may be very diverse, ranging from altruistic ones related to the desire of free sharing of Internet connectivity and various forms of activism to personal benefits from the experience and expertise through the active participation in the deployment and management of a real and operational network.

4.3. Governance and Sustainability Model

Different governance models are present in Alternative Networks. They may range from some open and horizontal models, with an active participation of the users (e.g., Community Networks) to a more centralized model, where a single authority (e.g., a company or a public stakeholder) plans and manages the network, even if it is (total or partially) owned by a community.

Regarding sustainability, some networks grow "organically" as a result of the new users who join and extend the network, contributing their own hardware. In some other cases, the existence of previous infrastructure (owned by the community or the users) may lower the capital expenditures of an operator, who can therefore provide the service with better economic conditions.

4.4. Technologies Employed

o Standard Wi-Fi. Many Alternative Networks are based on the standard IEEE 802.11 [IEEE.802.11] using the Distributed Coordination Function.

o Wi-Fi-based Long Distance (WiLD) networks. These can work with either Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) or an alternative Time Division Multiple Access (TDMA) Media Access Control (MAC) [Simo_b].

o TDMA. It can be combined with a Wi-Fi protocol, in a non-standard way [airMAX]. This configuration allows each client to send and receive data using pre-designated timeslots.

o 802.16-compliant (Worldwide Interoperability for Microwave Access (WiMax)) [IEEE.802.16] systems over non-licensed bands.

o Dynamic Spectrum Solutions (e.g., based on the use of TV White Spaces). A set of television frequencies that can be utilized by secondary users in locations where they are unused, e.g., IEEE 802.11af [IEEE.802.11AF] or 802.22 [IEEE.802.22].

o Satellite solutions can also be employed to give coverage to wide
   areas, as proposed in the RIFE project (https://rife-project.eu/).

o Low-cost optical fiber systems are also used to connect households
   in different places.

4.5. Typical Scenarios

The scenarios where Alternative Networks are usually deployed can be
classified as:

o Urban/rural areas.

o "Global north" / "global south" countries.

5. Classification of Alternative Networks

This section classifies Alternative Networks according to the
criteria explained previously. Each of them has different incentive
structures, maybe common technological challenges, but most
importantly interesting usage challenges that feed into the
incentives as well as the technological challenges.

At the beginning of each subsection, a table is presented including a
classification of each network according to the criteria listed in
the "Classification Criteria" subsection. Real examples of each kind
of Alternative Network are cited.

5.1. Community Networks

```
+----------------+-------------------------------------------------+
| Entity behind  | community                                       |
| the network    |                                                 |
+----------------+-------------------------------------------------+
| Purpose        | all the goals listed in Section 4.2 may be      |
|                | present                                         |
+----------------+-------------------------------------------------+
| Governance and | participatory administration model: non-        |
| sustainability | centralized and open building and maintenance;  |
| model          | users may contribute their own hardware         |
+----------------+-------------------------------------------------+
| Technologies   | Wi-Fi [IEEE.802.11] (standard and non-standard  |
| employed       | versions) and optical fiber                     |
+----------------+-------------------------------------------------+
| Typical        | urban and rural                                 |
| scenarios      |                                                 |
+----------------+-------------------------------------------------+
```

           Table 1: Characteristics Summary for Community Networks

Community Networks are non-centralized, self-managed networks sharing
these characteristics:

o They start and grow organically, and they are open to
   participation from everyone, sharing an open participation
   agreement. Community members directly contribute active (not just
   passive) network infrastructure. The network grows as new hosts
   and links are added.

o Knowledge about building and maintaining the network and ownership
   of the network itself is non-centralized and open. Different
   degrees of centralization can be found in Community Networks. In
   some of them, a shared platform (e.g., a website) may exist where
   minimum coordination is performed. Community members with the
   right permissions have an obvious and direct form of
   organizational control over the overall organization of the
   network (e.g., IP addresses, routing, etc.) in their community
   (not just their own participation in the network).

o The network can serve as a backhaul for providing a whole range of
   services and applications, from completely free to even commercial
   services.

Hardware and software used in Community Networks can be very diverse and customized, even inside one network. A Community Network can have both wired and wireless links. Multiple routing protocols or network topology management systems may coexist in the network.

These networks grow organically, since they are formed by the aggregation of nodes belonging to different users. A minimal governance infrastructure is required in order to coordinate IP addressing, routing, etc. Several examples of Community Networks are described in [Braem]. A technological analysis of a Community Network is presented in [Vega_b], which focuses on technological network diversity, topology characteristics, the evolution of the network over time, robustness and reliability, and networking service availability.

These networks follow a participatory administration model, which has been shown to be effective in connecting geographically dispersed people, thus enhancing and extending digital Internet rights.

Users adding new infrastructure (i.e., extensibility) can be used to formulate another definition: A Community Network is a network in which any participant in the system may add link segments to the network in such a way that the new segments can support multiple nodes and adopt the same overall characteristics as those of the joined network, including the capacity to further extend the network. Once these link segments are joined to the network, there is no longer a meaningful distinction between the previous and the new extent of the network. The term "participant" refers to an individual, who may become the user, provider, and manager of the network at the same time.

In Community Networks, profit can only be made by offering services and not simply by supplying the infrastructure, because the infrastructure is neutral, free, and open (mainstream Internet Service Providers base their business on the control of the infrastructure). In Community Networks, everybody usually keeps the ownership of what he/she has contributed or leaves the stewardship of the equipment to the network as a whole (the commons), even loosing track of the ownership of a particular equipment itself, in favor of the community.

The majority of Community Networks comply with the definition of Free Network, included in Section 2.

5.2. Wireless Internet Service Providers (WISPs)

```
+----------------+--------------------------------------------------+
| Entity behind  | company                                          |
| the network    |                                                  |
+----------------+--------------------------------------------------+
| Purpose        | to serve underserved areas; to reduce capital    |
|                | expenditures in Internet access; and to provide  |
|                | additional sources of capital                    |
+----------------+--------------------------------------------------+
| Governance and | operated by a company that provides the          |
| sustainability | equipment; centralized administration            |
| model          |                                                  |
+----------------+--------------------------------------------------+
| Technologies   | wireless, e.g., [IEEE.802.11] and [IEEE.802.16]  |
| employed       | and unlicensed frequencies                       |
+----------------+--------------------------------------------------+
| Typical        | rural (urban deployments also exist)             |
| scenarios      |                                                  |
+----------------+--------------------------------------------------+
```

                Table 2: Characteristics Summary for WISPs

   WISPs are commercially operated wireless Internet networks that
   provide Internet and/or Voice over Internet (VoIP) services. They
   are most common in areas not covered by mainstream telecommunications
   companies or ISPs. WISPs mostly use wireless point-to-multipoint
   links using unlicensed spectrum but often must resort to licensed
   frequencies. Use of licensed frequencies is common in regions where
   unlicensed spectrum is either perceived to be crowded or too
   unreliable to offer commercial services, or where unlicensed spectrum
   faces regulatory barriers impeding its use.

   Most WISPs are operated by local companies responding to a perceived
   market gap. There is a small but growing number of WISPs, such as
   [Airjaldi] in India, that have expanded from local service into
   multiple locations.

   Since 2006, the deployment of cloud-managed WISPs has been possible
   with hardware from companies such as [Meraki] and later [OpenMesh]
   and others. Until recently, however, most of these services have
   been aimed at "global north" markets. In 2014, a cloud-managed WISP
   service aimed at "global south" markets was launched [Everylayer].

5.3. Shared Infrastructure Model

+----------------+--+
| Entity behind | shared: companies and users |
| the network | |
+----------------+--+
Purpose	to eliminate a capital expenditures barrier (to
	operators); lower the operating expenses
	(supported by the community); and extend
	coverage to underserved areas
+----------------+--+
Governance and	the community rents the existing infrastructure
sustainability	to an operator
model	
+----------------+--+
Technologies	wireless in non-licensed bands, mobile
employed	femtocells, WiLD networks [WiLD], and/or low-
	cost fiber
+----------------+--+
| Typical | rural areas, and more particularly rural areas |
| scenarios | in "global south" regions |
+----------------+--+

        Table 3: Characteristics Summary for Shared Infrastructure

   In mainstream networks, the operator usually owns the
   telecommunications infrastructure required for the service or
   sometimes rents infrastructure to/from other companies. The problem
   arises in large areas with low population density, in which neither
   the operator nor the other companies have deployed infrastructure and
   such deployments are not likely to happen due to the low potential
   return on investment.

   When users already own deployed infrastructure, either individually
   or as a community, sharing that infrastructure with an operator can
   benefit both parties and is a solution that has been deployed in some
   areas. For the operator, this provides a significant reduction in
   the initial investment needed to provide services in small rural
   localities because capital expenditure is only associated with the
   access network. Renting capacity in the users' network for
   backhauling only requires an increment in the operating expenditure.
   This approach also benefits the users in two ways: they obtain
   improved access to telecommunications services that would not be
   accessible otherwise, and they can derive some income from the
   operator that helps to offset the network's operating costs,
   particularly for network maintenance.

One clear example of the potential of the "shared infrastructure
model" nowadays is the deployment of 3G services in rural areas in
which there is a broadband rural Community Network. Since the
inception of femtocells (small, low-power cellular base stations),
there are complete technical solutions for low-cost 3G coverage using
the Internet as a backhaul. If a user or community of users has an
IP network connected to the Internet with some excess capacity,
placing a femtocell in the user premises benefits both the user and
the operator, as the user obtains better coverage and the operator
does not have to support the cost of the backhaul infrastructure.
Although this paradigm was conceived for improved indoor coverage,
the solution is feasible for 3G coverage in underserved rural areas
with low population density (i.e., villages), where the number of
simultaneous users and the servicing area are small enough to use
low-cost femtocells. Also, the amount of traffic produced by these
cells can be easily transported by most community broadband rural
networks.

Some real examples can be referenced in the TUCAN3G project, which
deployed demonstrator networks in two regions in the Amazon forest in
Peru [Simo_d]. In these networks [Simo_a], the operator and several
rural communities cooperated to provide services through rural
networks built up with WiLD links [WiLD]. In these cases, the
networks belonged to the public health authorities and were deployed
with funds that came from international cooperation for telemedicine
purposes. Publications that justify the feasibility of this approach
can also be found on that website.

5.4. Crowdshared Approaches Led by the Users and Third-Party
      Stakeholders

```
+----------------+--------------------------------------------------+
| Entity behind  | community, public stakeholders, private          |
| the network    | companies, and supporters of a crowdshared       |
|                | approach                                         |
+----------------+--------------------------------------------------+
| Purpose        | sharing connectivity and resources               |
+----------------+--------------------------------------------------+
| Governance and | users share their capacity, coordinated by a     |
| sustainability | Virtual Network Operator (VNO); different models |
| model          | may exist, depending on the nature of the VNO    |
+----------------+--------------------------------------------------+
| Technologies   | Wi-Fi [IEEE.802.11]                              |
| employed       |                                                  |
+----------------+--------------------------------------------------+
| Typical        | urban and rural                                  |
| scenarios      |                                                  |
+----------------+--------------------------------------------------+
```

         Table 4: Characteristics Summary for Crowdshared Approaches

   These networks can be defined as a set of nodes whose owners share
   common interests (e.g., sharing connectivity; resources; and
   peripherals) regardless of their physical location. They conform to
   the following approach: the home router creates two wireless networks
   -- one of them is normally used by the owner, and the other one is
   public. A small fraction of the bandwidth is allocated to the public
   network to be employed by any user of the service in the immediate
   area. Some examples are described in [PAWS] and [Sathiaseelan_c].
   Other examples are found in the networks created and managed by city
   councils (e.g., [Heer]). The "openwireless movement"
   (https://openwireless.org/) also promotes the sharing of private
   wireless networks.

   Some companies [Fon] also promote the use of Wi-Fi routers with dual
   access: a Wi-Fi network for the user and a shared one. Adequate
   Authentication, Authorization, and Accounting (AAA) policies are
   implemented, so people can join the network in different ways: they
   can buy a router, so they can share their connection and in turn,
   they get access to all the routers associated with the community.
   Some users can even get some revenue every time another user connects
   to their Wi-Fi Access Point. Users that are not part of the
   community can buy passes in order to use the network. Some
   mainstream telecommunications operators collaborate with these

communities by including the functionality required to create the two
access networks in their routers. Some of these efforts are surveyed
in [Shi].

The elements involved in a crowdshared network are summarized below:

o Interest: A parameter capable of providing a measure (cost) of the
   attractiveness of a node in a specific location, at a specific
   instance in time.

o Resources: A physical or virtual element of a global system. For
   instance, bandwidth; energy; data; and devices.

o The owner: End users who sign up for the service and share their
   network capacity. As a counterpart, they can access another
   owner's home network capacity for free. The owner can be an end
   user or an entity (e.g., operator; virtual mobile network
   operator; or municipality) that is to be made responsible for any
   actions concerning his/her device.

o The user: A legal entity or an individual using or requesting a
   publicly available electronic communications service for private
   or business purposes, without necessarily having subscribed to
   such service.

o The VNO: An entity that acts in some aspects as a network
   coordinator. It may provide services such as initial
   authentication or registration and, eventually, trust relationship
   storage. A VNO is not an ISP given that it does not provide
   Internet access (e.g., infrastructure or naming). A VNO is not an
   Application Service Provider (ASP) either since it does not
   provide user services. VNOs may also be stakeholders with socio-
   environmental objectives. They can be local governments,
   grassroots user communities, charities, or even content operators,
   smart grid operators, etc. They are the ones who actually run the
   service.

o Network operators: They have a financial incentive to lease out
   unused capacity [Sathiaseelan_b] at a lower cost to the VNOs.

VNOs pay the sharers and the network operators, thus creating an
incentive structure for all the actors: the end users get money for
sharing their network, and the network operators are paid by the
VNOs, who in turn accomplish their socio-environmental role.

5.5. Rural Utility Cooperatives

```
+-----------------------+----------------------------------------------+
| Entity behind the     | rural utility cooperative                    |
| network               |                                              |
+-----------------------+----------------------------------------------+
| Purpose               | to serve underserved areas and to reduce     |
|                       | capital expenditures in Internet access      |
+-----------------------+----------------------------------------------+
| Governance and        | the cooperative partners with an ISP who     |
| sustainability        | manages the network                          |
| model                 |                                              |
+-----------------------+----------------------------------------------+
| Technologies          | wired (fiber) and wireless                   |
| employed              |                                              |
+-----------------------+----------------------------------------------+
| Typical scenarios     | rural                                        |
+-----------------------+----------------------------------------------+
```

       Table 5: Characteristics Summary for Rural Utility Cooperatives

   A utility cooperative is a type of cooperative that delivers a public
   utility to its members. For example, in the United States, rural
   electric cooperatives have provided electric service starting in the
   1930s, especially in areas where investor-owned utility would not
   provide service, believing there would be insufficient revenue to
   justify the capital expenditures required. Similarly, in many
   regions with low population density, traditional Internet Service
   Providers such as telephone companies or cable TV companies are
   either not providing service at all or only offering low-speed DSL
   service. Some rural electric cooperatives started installing fiber
   optic lines to run their smart grid applications, but they found they
   could provide fiber-based broadband to their members at little
   additional cost [Cash]. In some of these cases, rural electric
   cooperatives have partnered with local ISPs to provide Internet
   connection to their members [Carlson]. More information about these
   utilities and their management can be found in [NewMexico] and
   [Mitchell].

5.6. Testbeds for Research Purposes

```
+------------------+-----------------------------------------------+
| Entity behind    | research/academic entity                      |
| the network      |                                               |
+------------------+-----------------------------------------------+
| Purpose          | research                                      |
+------------------+-----------------------------------------------+
| Governance and   | the management is initially coordinated by the|
| sustainability   | research entity, but it may end up in a       |
| model            | different model                               |
+------------------+-----------------------------------------------+
| Technologies     | wired and wireless                            |
| employed         |                                               |
+------------------+-----------------------------------------------+
| Typical          | urban and rural                               |
| scenarios        |                                               |
+------------------+-----------------------------------------------+
```

              Table 6: Characteristics Summary for Testbeds

   In some cases, the initiative to start the network is not from the
   community but from a research entity (e.g., a university), with the
   aim of using it for research purposes [Samanta] [Bernardi].

   The administration of these networks may start being centralized in
   most cases (administered by the academic entity) and may end up in a
   non-centralized model in which other local stakeholders assume part
   of the network administration (for example, see [Rey]).

6. Technologies Employed

6.1. Wired

   In many ("global north" or "global south") countries, it may happen
   that national service providers decline to provide connectivity to
   tiny and isolated villages. So in some cases, the villagers have
   created their own optical fiber networks. This is the case in
   Lowenstedt, Germany [Lowenstedt] or in some parts of Guifi.net
   [Cerda-Alabern].

6.2. Wireless

   The vast majority of Alternative Network Deployments are based on
   different wireless technologies [WNDW]. Below we summarize the
   options and trends when using these features in Alternative Networks.

6.2.1. Media Access Control (MAC) Protocols for Wireless Links

   Different protocols for MAC, which also include physical layer (PHY)
   recommendations, are widely used in Alternative Network Deployments.
   Wireless standards ensure interoperability and usability to those who
   design, deploy, and manage wireless networks. In addition, they then
   ensure the low cost of equipment due to economies of scale and mass
   production.

   The standards used in the vast majority of Alternative Networks come
   from the IEEE Standard Association's IEEE 802 Working Group.
   Standards developed by other international entities can also be used,
   such as, e.g., the European Telecommunications Standards Institute
   (ETSI).

6.2.1.1. 802.11 (Wi-Fi)

   The standard we are most interested in is 802.11 a/b/g/n/ac, as it
   defines the protocol for Wireless LAN. It is also known as "Wi-Fi".
   The original release (a/b) was issued in 1999 and allowed for rates
   up to 54 Mbit/s. The latest release (802.11ac) approved in 2013
   reaches up to 866.7 Mbit/s. In 2012, the IEEE issued an 802.11
   standard that consolidated all the previous amendments [IEEE.802.11].
   The document is freely downloadable from the IEEE Standards
   Association [IEEE].

   The MAC protocol in 802.11 is called CSMA/CA and was designed for
   short distances; the transmitter expects the reception of an
   acknowledgment for each transmitted unicast packet and if a certain
   waiting time is exceeded, the packet is retransmitted. This behavior
   makes necessary the adaptation of several MAC parameters when 802.11
   is used in long links [Simo_b]. Even with this adaptation, distance
   has a significant negative impact on performance. For this reason,
   many vendors implement alternative medium access techniques that are
   offered alongside the standard CSMA/CA in their outdoor 802.11
   products. These alternative proprietary MAC protocols usually employ
   some type of TDMA. Low-cost equipment using these techniques can
   offer high throughput at distances above 100 kilometers.

   Different specifications of 802.11 operate in different frequency
   bands. 802.11b/g/n operates in 2.4 GHz, but 802.11a/n/ac operates in
   5 GHz. This fact is used in some Community Networks in order to
   separate ordinary and "backbone" nodes:

   o Typical routers running mesh firmware in homes, offices, and
      public spaces operate at 2.4 GHz.

   o Special routers running mesh firmware as well but broadcasting and
      receiving on the 5 GHz band are used in point-to-point connections
      only. They are helpful to create a "backbone" on the network that
      can both connect neighborhoods to one another when reasonable
      connections with 2.4 GHz nodes are not possible, and they ensure
      that users of 2.4 GHz nodes are within a few hops to strong and
      stable connections to the rest of the network.

6.2.1.2. Mobile Technologies

   Global System for Mobile Communications (GSM), from ETSI, has also
   been used in Alternative Networks as a Layer 2 option, as explained
   in [Mexican], [Village], and [Heimerl]. Open source GSM code
   projects such as OpenBTS (http://openbts.org) or OpenBSC
   (http://openbsc.osmocom.org/trac/) have created an ecosystem with the
   participation of several companies such as, e.g., [Rangenetworks],
   [Endaga], and [YateBTS]. This enables deployments of voice, SMS, and
   Internet services over Alternative Networks with an IP-based
   backhaul.

   Internet navigation is usually restricted to relatively low bit rates
   (see, e.g., [Osmocom]). However, leveraging on the evolution of
   Third Generation Partnership Project (3GPP) standards, a trend can be
   observed towards the integration of 4G [Spectrum] [YateBTS] or 5G
   [Openair] functionalities, with significant increase of achievable
   bit rates.

   Depending on factors such as the allocated frequency band, the
   adoption of licensed spectrum can have advantages over the eventually
   higher frequencies used for Wi-Fi, in terms of signal propagation
   and, consequently, coverage. Other factors favorable to 3GPP
   technologies, especially GSM, are the low cost and energy consumption
   of handsets, which facilitate its use by low-income communities.

6.2.1.3. Dynamic Spectrum

   Some Alternative Networks make use of TV White Spaces [Lysko] -- a
   set of UHF and VHF television frequencies that can be utilized by
   secondary users in locations where they are unused by licensed
   primary users such as television broadcasters. Equipment that makes
   use of TV White Spaces is required to detect the presence of existing
   unused TV channels by means of a spectrum database and/or spectrum
   sensing in order to ensure that no harmful interference is caused to
   primary users. In order to smartly allocate interference-free
   channels to the devices, cognitive radios are used that are able to
   modify their frequency, power, and modulation techniques to meet the
   strict operating conditions required for secondary users.

The use of the term "White Spaces" is often used to describe "TV
White Spaces" as the VHF and UHF television frequencies were the
first to be exploited on a secondary use basis. There are two
dominant standards for TV White Space communication: (i) the 802.11af
standard [IEEE.802.11AF] -- an adaptation of the 802.11 standard for
TV White Space bands -- and (ii) the IEEE 802.22 standard
[IEEE.802.22] for long-range rural communication.

6.2.1.3.1. 802.11af

802.11af [IEEE.802.11AF] is a modified version of the 802.11 standard
operating in TV White Space bands using cognitive radios to avoid
interference with primary users. The standard is often referred to
as "White-Fi" or "Super Wi-Fi" and was approved in February 2014.
802.11af contains much of the advances of all the 802.11 standards
including recent advances in 802.11ac such as up to four bonded
channels, four spatial streams, and very high-rate 256 QAM
(Quadrature Amplitude Modulation) but with improved in-building
penetration and outdoor coverage. The maximum data rate achievable
is 426.7 Mbit/s for countries with 6/7 MHz channels and 568.9 Mbit/s
for countries with 8 MHz channels. Coverage is typically limited to
1 km although longer range at lower throughput and using high gain
antennas will be possible.

Devices are designated as enabling stations (Access Points) or
dependent stations (clients). Enabling stations are authorized to
control the operation of a dependent station and securely access a
geolocation database. Once the enabling station has received a list
of available White Space channels, it can announce a chosen channel
to the dependent stations for them to communicate with the enabling
station. 802.11af also makes use of a registered location server -- a
local database that organizes the geographic location and operating
parameters of all enabling stations.

6.2.1.3.2. 802.22

802.22 [IEEE.802.22] is a standard developed specifically for long-
range rural communications in TV White Space frequencies and was
first approved in July 2011. The standard is similar to the 802.16
(WiMax) [IEEE.802.16] standard with an added cognitive radio ability.
The maximum throughput of 802.22 is 22.6 Mbit/s for a single 8 MHz
channel using 64-QAM modulation. The achievable range using the
default MAC scheme is 30 km; however, 100 km is possible with special
scheduling techniques. The MAC of 802.22 is specifically customized
for long distances -- for example, slots in a frame destined for more
distant Consumer Premises Equipment (CPE) are sent before slots
destined for nearby CPEs.

Base stations are required to have a Global Positioning System (GPS)
and a connection to the Internet in order to query a geolocation
spectrum database. Once the base station receives the allowed TV
channels, it communicates a preferred operating TV White Space
channel with the CPE devices. The standard also includes a
coexistence mechanism that uses beacons to make other 802.22 base
stations aware of the presence of a base station that is not part of
the same network.

7. Upper Layers

7.1. Layer 3

7.1.1. IP Addressing

Most Community Networks use private IPv4 address ranges, as defined
by [RFC1918]. The motivation for this was the lower cost and the
simplified IP allocation because of the large available address
ranges.

Most known Alternative Networks started in or around the year 2000.
IPv6 was fully specified by then, but almost all Alternative Networks
still use IPv4. A survey [Avonts] indicated that IPv6 rollout
presented a challenge to Community Networks. However, some of them
have already adopted it, such as ninux.org.

7.1.2. Routing Protocols

As stated in previous sections, Alternative Networks are composed of
possibly different Layer 2 devices, resulting in a mesh of nodes. A
connection between different nodes is not guaranteed, and the link
stability can vary strongly over time. To tackle this, some
Alternative Networks use mesh routing protocols for Mobile Ad Hoc
Networks (MANETs), while other ones use more traditional routing
protocols. Some networks operate multiple routing protocols in
parallel. For example, they may use a mesh protocol inside different
islands and rely on traditional routing protocols to connect these
islands.

7.1.2.1. Traditional Routing Protocols

The Border Gateway Protocol (BGP), as defined by [RFC4271], is used
by a number of Community Networks because of its well-studied
behavior and scalability.

For similar reasons, smaller networks opt to run the Open Shortest
Path First (OSPF) protocol, as defined by [RFC2328].

7.1.2.2. Mesh Routing Protocols

   A large number of Alternative Networks use customized versions of the
   Optimized Link State Routing (OLSR) Protocol [RFC3626]. The open
   source project [OLSR] has extended the protocol with the Expected
   Transmission Count (ETX) metric [Couto] and other features for its
   use in Alternative Networks, especially wireless ones. A new version
   of the protocol, named OLSRv2 [RFC7181], is becoming used in some
   Community Networks [Barz].

   Better Approach To Mobile Ad Hoc Networking (B.A.T.M.A.N.) Advanced
   [Seither] is a Layer 2 routing protocol, which creates a bridged
   network and allows seamless roaming of clients between wireless
   nodes.

   Some networks also run the BatMan-eXperimental Version 6 (BMX6)
   protocol [Neumann_a], which is based on IPv6 and tries to exploit the
   social structure of Alternative Networks.

   Babel [RFC6126] is a Layer 3 loop-avoiding distance-vector routing
   protocol that is robust and efficient both in wired and wireless mesh
   networks.

   In [Neumann_b], a study of three proactive mesh routing protocols
   (BMX6, OLSR, and Babel) is presented, in terms of scalability,
   performance, and stability.

7.2. Transport Layer

7.2.1. Traffic Management When Sharing Network Resources

   When network resources are shared (as, e.g., in the networks
   explained in Section 5.4), special care has to be taken with the
   management of the traffic at upper layers. From a crowdshared
   perspective, and considering just regular TCP connections during the
   critical sharing time, the Access Point offering the service is
   likely to be the bottleneck of the connection.

   This is the main concern of sharers, having several implications. In
   some cases, an adequate Active Queue Management (AQM) mechanism that
   implements a Less-than-Best-Effort (LBE) [RFC6297] policy for the
   user is used to protect the sharer. Achieving LBE behavior requires
   the appropriate tuning of well-known mechanisms such as Explicit
   Congestion Notification (ECN) [RFC3168], Random Early Detection (RED)
   [RFC7567], or other more recent AQM mechanisms that aid low latency
   such as Controlled Delay (CoDel) [CoDel] and Proportional Integral
   controller Enhanced (PIE) [PIE] design.

7.3. Services Provided

   This section provides an overview of the services provided by the
   network. Many Alternative Networks can be considered Autonomous
   Systems, being (or aspiring to be) a part of the Internet.

   The services provided can include, but are not limited to:

   o Web browsing.

   o Email.

   o Remote desktop (e.g., using my home computer and my Internet
      connection when I am away).

   o FTP file sharing (e.g., distribution of software and media).

   o VoIP (e.g., with SIP).

   o Peer-to-Peer (P2P) file sharing.

   o Public video cameras.

   o DNS.

   o Online game servers.

   o Jabber instant messaging.

   o Weather stations.

   o Network monitoring.

   o Videoconferencing/streaming.

   o Radio streaming.

   o Message/bulletin board.

   o Local cloud storage services.

   Due to bandwidth limitations, some services (file sharing, VoIP,
   etc.) may not be allowed in some Alternative Networks. In some of
   these cases, a number of federated proxies provide web-browsing
   service for the users.

Some specialized services have been specifically developed for
Alternative Networks:

o Inter-network peering/VPNs
   (e.g., https://wiki.freifunk.net/IC-VPN).

o Community-oriented portals (e.g., http://tidepools.co/).

o Network monitoring/deployment/maintenance platforms.

o VoIP sharing between networks, allowing cheap calls between
   countries.

o Sensor networks and citizen science built by adding sensors to
   devices.

o Community radio/TV stations.

Other services (e.g., local wikis as used in community portals; see
https://localwiki.org) can also provide useful information when
supplied through an Alternative Network, although they were not
specifically created for them.

7.3.1. Use of VPNs

Some "micro-ISPs" may use the network as a backhaul for providing
Internet access, setting up VPNs from the client to a machine with
Internet access.

Many Community Networks also use VPNs to connect multiple disjoint
parts of their networks together. In some others, every node
establishes a VPN tunnel as well.

7.3.2. Other Facilities

Other facilities, such as NTP or Internet Relay Chat (IRC) servers
may also be present in Alternative Networks.

7.4. Security Considerations

No security issues have been identified for this document.

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