A Survey of the Progress of Global Access to the Internet for All (GAIA)

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Abstract

This is a survey about the concept of Global Access to the Internet for All (GAIA). It discusses some previous attempts and proposed solutions. Then it discusses some of the challenges. This survey aims to give a big picture of the field of GAIA.

Keywords

GAIA, access to the internet, Project Loon, internet.org, guifi.net, approximate network, 5G, Great Firewall of China

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Table of Contents:

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1. Introduction

What are some of the greatest inventions of humanity? The Internet has to be on the list. As a powerful communicating tool, the Internet provides a way to create, store, and communicate information that is so efficient and revelational that it changes how we learn, work, entertain, get, and share information, and therefore changes humanity as a whole forever. The Internet deserves to be accessed by anyone, everyone. Otherwise, such an important tool will create a great inequality between people who have access to the internet and who do not. people that do not have access to the internet have a great disadvantage because their ability of information gathering is greatly limited by traditional communicating methods. This inequality will lead to a worse socio-economic problem. Unfortunately, nearly half of our population does not have access to the Internet [Kemp21].

To solve the problem of low global internet access rate, the concept of Global Access of the Internet for All (GAIA) is raised. This survey aims to discuss the concept of GAIA, some of the previous attempts to achieve GAIA, some proposed solutions to GAIA, and its challenges.

This survey discusses Google's Project Loon and Facebook's internet.org project. The former one is Google's attempts to launch balloons to the high attitude as Internet access points to provide global internet access; the latter one is Facebook's approach to provide free but limited internet access, which is controversial. This survey also talks about a decentralized solution: guifi.net, which has been growing rapidly and shows promise as a solution to GAIA. Then some of the proposed solutions from researchers will be presented. A concept of an approximate network that trade-offs quality for other advantages to better fit in the goal of GAIA will be discussed. Another solution to be discussed is the frugal 5G network architecture, which utilizes emerging 5G technology to cover the internet access capability in rural areas. Finally, this survey discusses some of the challenges of achieving GAIA. It focuses on the Great Firewall of China, which separates a large number of users from freely accessing the Internet. Throughout these discussions, this paper gives a general picture of the progress of GAIA.

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2. The Concept of GAIA

The concept of Global Access to the Internet for All (GAIA) was proposed by An IRTF (Internet Research Task Force) sub-group with the same name -- GAIA. The goal of GAIA is to find ways to provide internet access to everyone by proposing and evaluating possible solutions as well as examining existing technologies that have a possibility to achieve the goal.

2.1 The origin of GAIA -- IRTF

IRTF is a research organization with 14 sub-groups, each of which focuses on a different topic related to the internet. This organization focuses on researches related to long-term issues that pertain to the development and application of the internet. Research topics of IRTF are regulated by RFC 7418, which is an RFC document that brings up factors to be considered if IETF (Internet Engineering Task Force), a paralleled organization, wants to propose new research

topics into IRTF. Therefore, RFC 7418 also serves as an explanation for the differences between IRTF and IETF.

2.2 GAIA as a research group of IRTF

As one of the 14 active research groups of IRTF, GAIA is treated as an important research topic that relates to the long-term development of the internet. According to the Internet Society's Global Internet User Survey 2012 [Internet Society12], having access to the internet is considered a human right. GAIA researches aim to tackle the challenges that stop people from accessing the internet. Those challenges come from a wide variety of fields: Socio-economic barriers such as expensive ISP (Internet Service Provider) fees, under-developed internet infrastructure; political barriers such as government restrictions; geographic barriers such as internet access for remote/rural areas. Those challenges need to be tackled before the disparity of people from who can have internet access and who cannot convolute to worse problems.

To tackle those challenges, the objectives of the GAIA research sub-group can be summed up into the following points [IETF16]:

- Encouraging global internet access regards to technology, social and economic factors;
- Providing a shared vision;
- Addressing challenges such as privacy, security, censorship, etc.;
- Sharing research results and experiences through academic methods;
- Documenting and breaking down, and finding a solution of 10x cost reduction.
- Establishing standards that regard GAIA technology.

GAIA research group had its first meeting on October 6, 2014. Since then, it has been a leader in researches that aim to provide general internet access for everyone.

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3. Previous Attempts

GAIA has been recognized as an important issue to be solved around the world. There have been some attempts to achieve internet access for all. Google's famous Project Loon might be the most representative attempt to GAIA. Facebook has its internet.org project that tried to provide GAIA. Members of Guifi.net launched a crowdsourced-based community network. Having a conversation about previous attempts is important because those projects have or had launched in a real-world environment, their performance is crucial for the measurement of many factors about GAIA.

3.1 Google's Project Loon

Google's solution to GAIA was Project Loon. Announced in June 2013 [Andurkar16], but began in around 2011, Project Loon was the hope to solve the GAIA problem once and for all. The concept was innovative and groundbreaking: instead of relying on local ISPs and their

infrastructures around the world to connect to the internet, Project Loon tried to launch a large number of balloons that float around the globe as access points. This concept had great potential because one of the biggest barriers to GAIA -- the geographic barriers can be circumvented entirely. It was expected to improve global internet connection, including rural areas, dramatically. Backed by Google, one of the biggest technology companies, Project Loon had an opportunity to become one of the most important events in the history of the internet.

The project gained some substantial successes during its initial trial. It gained attention when providing internet access in Puerto Rico in 2017 and Peru in 2019. However, mainly due to cost-efficient and scale-up issues, the company decided that this project need to be discontinued, and announced its end in January 2021 [Swinhoe21].

Google believed that the ultimate goal of Project Loon is to connect 4.5 billion people that do not have internet access. To tackle this ambitious goal, Project Loon was equipped with some state-of-the-art technology. Their general idea was creative: flying balloons at high altitudes ignore challenges from complicated geographic factors that traditional internet access infrastructures are facing. Balloons were deployed 32 km above the surface, way above commercial flight paths, avoided weather factors like wind and rains at the same time.

Balloons were solar-powered, capable of providing 3G internet speed. Each balloon can cover 40 km in diameter and hundreds of people [Andurkar16]. One can easily see that to connect over 4.5 billion people around the world, a single unit of balloons has a wanting capability. It implies that the scale-up problem of this concept is hard to solve. Actually, by the end of this project, the capability of a single balloon has been largely improved: it can cover 11,000 km2 and provide 4G LTE speed [Koziol21]. Unfortunately, improvements in technologies still cannot meet the scale-up requirements. The company also found out that they could not find a way to lower the cost, especially for under-developed regions. the monthly fee to access the internet via Project Loon was still too high for some regions. Since the company could not find a solution for these challenges, Project Loon was closed.

3.2 Facebook's internet.org Project

If we treat Project Loon as an experiment for this topic, the result would be: One of the most difficult challenges of achieving GAIA is the cost. In 2014, Facebook launched its GAIA program: the internet.org program [Futter15]. Although it seems to be similar to Project Loon, it is actually dramatically different. internet.org project is low-cost by design but is much more controversial than Project Loon.

One of the most significant differences between internet.org and Project Loon is that internet.org is not an "internet access solution" in a conventional mean: it only provides users with a "basic internet connection". Instead of giving its users full access to the internet, it only provides some "basic internet services" like Facebook, Facebook Messenger, a collection of essential websites that pertains to health, finance, news, etc. [Futter15]. In return for this limitation, internet.org is free of charge. To implement this basic but free service, Facebook chose a less technologically inclined approach: by collaborating with companies and governments around the world.

This approach is controversial. Some critics think this is not a solution to GAIA because users do not actually have access to the internet. It violates the "free" principle of the internet because users are being controlled from freely choosing what content to access. But some counterarguments states that it is still better than none. By limiting the functionalities, internet.org can operate at a very low cost, and provide free service.

One might find out a big disadvantage of collaborating with local institutions: it relies on the local infrastructures for internet access. i.e., it does not break the geographic barriers of GAIA. To overcome this disadvantage, Facebook developed Aquilla, a type of unmanned solar-powered drone as an internet access point. This solution is better than balloons in the following ways: it can fly to an appointed location directly, which brings a great amount of flexibility for deployment according to users' density. It can land easily, hence lowering the cost of maintenance. internet.org project is a trade-off between how many people can have access to the internet and the limitation of contents while having access.

3.2 Facebook's internet.org Project

Google's Project Loon and Facebook's internet.org project are GAIA solutions that are proposed and executed by companies. They are centralized solutions that come with disadvantages from this concept: Those projects are led by and rely on companies, a kind of profit-driven organization by nature. Their life cycles are depended on companies' decisions. When it comes to solutions to a large population on the internet, the concept of decentralization can often provide great answers. P2P protocol is a great solution for online content hosting and sharing, Onion Browser uses this concept to implement an anonymous internet access solution, and blockchain technologies are hot topics as the future of a trading system. Will the concept of decentralization have a solution for GAIA?

Community network is the answer to decentralization. A community network is a bottom-up IP-based network structure that can be built, operated, and used by community members. Those networks are usually operated by a local non-profit organization and provide internet access and other network services. Starting in 2004, guifi.net is the largest community network in the world. As of November 2021, guifi.net has more than 37,200 working nodes and 13,400 users [Guifi21].

guifi.net describes itself as a bottom-up network technology that is free, open, and neutral to provide internet access [Guifi21]. Since most of the connections within guifi.net are wireless, it is also the largest wireless community network. The core technology of the implementation is the common pool resource (CPR) model [Baig15]. It is operated under a simple protocol: new members are given access to the internet via the network and the rights to know any information about the network, with only one limitation: members cannot affect the freedom of other users. This protocol is propagational, i.e., members can extend the network following the same protocol.

The network connects its proxy services to ISPs as a gateway. RFC 1918 IPv4 private addresses are used within guifi.net. end-user nodes are connected to supernodes, which connect each other as a backbone of the network. They are usually connected via Wi-Fi or optical cables. The

routing mechanism consists of an implementation of Open Shortest Path First (OSPF) with Boarder Gateway Protocol (BGP) [Vega15].

guifi.net grows at a high speed. On average, about 30 nodes joined the network weekly [Guifi21], 27 nodes were joined during the second week of November 2021. [Baig15]

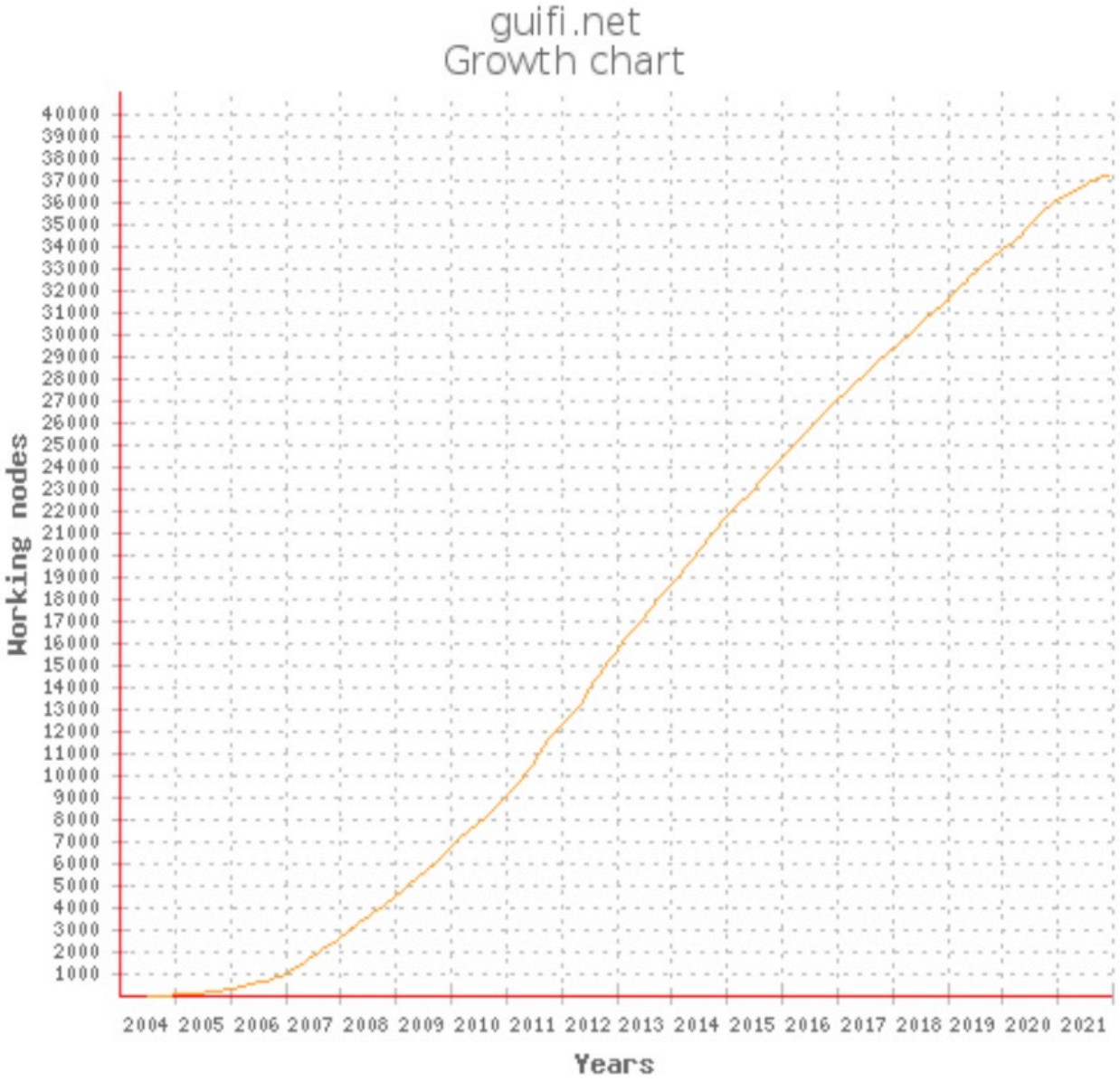

Fig 1. The growth of guifi.net. We can see that the nodes increase dramatically over years [Baig15].

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4. Proposed solutions

From the previous discussion, one can see that achieving GAIA is a challenging task. Luckily, many solutions have been proposed. Some of them focus on a new network structure, e.g., the alternate network and approximate network, some focus on utilizing new technologies like 5G network.

4.1 Approximate Network

From all the previous attempts, we can see that it is difficult to bring a high-quality and fully functional network connection to everyone. What if we take a step back and make some trade-offs? What if instead of connecting all people to a high-speed network, we focus on connecting to a good enough, but much more cost-efficient therefore approachable network?

Proposed by J. Qadir et al., [Qadir16] approximate network is a general network design guideline for cost-efficient and "good enough" network construction. Costing is an unavoidable challenge to GAIA, even projects that gained global attention and supports as Project Loon failed due to cost problems. Proposers of the approximate network believe that a high-speed and fully functional network for everyone is unachievable. But if some trade-offs can be made, a lighter version of internet access for all could be achieved. Approximate networks are networks that do trade-offs from quality to accessibility [Qadir16].

Hardware that is being used in approximate networks usually trade-offs accuracy of computations for energy efficiency. Considering the diminishing in return in accuracy and power consumption, sacrificing some accuracy for a "good enough" performance can achieve higher marginal gain from power consumption. A similar principle can be applied to the software design of approximate networks. If some of the error-correcting mechanisms can be relieved, the cost can be dramatically reduced. One of the most common trade-offs in approximate network software is to deliver data that may contain errors to upper layers.

4.2 Frugal 5G network architecture

Emerging new network technology like 5G could be a key to the solution of GAIA. M. Khaturia et al. proposed the frugal 5G network architecture [Khaturia20], a solution to internet access in rural areas. The challenge of rural area internet infrastructure construction is the long distance between villages, with no residents in between, a large number of villages sparse through a large area. It is unfeasible to use conventional infrastructure design to cover that area, but frugal 5G network architecture is tailored for this scenario.

The general idea is to connect a cluster, e.g., a village, via a combination of 5G radio and WLAN. Then there will be multiple clusters in a large rural area. Each cluster has a middle mile client (in the form of a tower) that uses Ethernet links to connect those WLAN networks. The connection between those middle mile clients serves as a great solution to travel through rural areas. Those middle mile clients constitute a middle mile network, which has an access point that connects to the internet through Fiber Point of Presence (PoP). [Onireti16]

Researchers constructed two testbeds in India for this architecture and received satisfactory results. This architecture is affordable because of the usage of WLAN and the flexibility of the

access point control. It is tailored to rural internet access scenario: multiple clusters separation achieves high-speed connection via WLAN. The middle mile clients and WLAN nodes are capable to use renewable energy to be eco-friendly. Cache in the access points provides local storage. [Onireti16] Researchers believe that this architecture fulfills the requirements for a rural network infrastructure.

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5. Challenges

The necessity of GAIA is undoubtful. However, an ideal solution has yet to be found. We have discussed some of the technology to achieve GAIA and some challenges in those proposed solutions. The second A in GAIA stands for all, which is an ambitious goal. Throughout the history of humanity, it is hard to find an example that we achieve something for all people. In this essence, solving the GAIA problem might be as hard as solving some of the hardest problems for humanity, e.g., the starvation problem and peace-making problem. The scale-up factor could make GAIA difficult to solve because it involves everyone.

Besides those challenges we have discussed, there is an important one that other GAIA researchers have rarely mentioned: The government restriction, to be more specific, the Great Firewall of China.

5.1 An isolated network

The most important feature of the internet is connections. Internet is powerful because it connects people and conveys information in a ground-breaking way that humanity has never seen before. There are 4.66 billion users on the internet. [Kemp 2021] What if 988 million of them are separated from the rest? If they are isolated from the rest of the world, cannot access some of the most frequently used services like Google and YouTube, would it be a problem for GAIA?

Sadly, this is a fact: those 988 million people are internet users from China, their internet access is restricted by their government via the Great Firewall of China. A large amount of internet users is currently being separated from the rest. They are absent from some of the most popular social media like Twitter, Facebook, and YouTube.

5.2 The Great Firewall of China (GFW)

Starting in 2003 [Ensafi15], some users in China started to encounter difficulties while trying to access some online services. It appeared to be some normal network congestions like receiving HTTP 404 or connection time out but it is actually the implementation of GFW.

GFW implemented multiple mechanisms in order to block users' access to particular sites. In its early stage, users in China found out that one of the mechanisms is DNS contamination. It is speculated that the DNS contaminations happen on DNS servers in mainland China. DNS

requests for specific destinations e.g., google.com will receive no response from DNS servers. The circumvention was straightforward: just establishing a local DNS table or attempting to connect via IP addresses.

However, the GFW has evolute and became sophisticated. Nowadays, it is a multi-level internet blockage that works on TCP/IP level, DNS requests, and HTTP requests. Researchers found out that the GFW blocks the SYN/ACKs packages that enter the country but does not block the SYNs that leave the country. [Ensafi15]

To make the matter worse, recent research found out that the GFW has the capability to discover hidden circumvention servers. [Fifield15] Some of the most common circumventions are VPNs and Tor Networks. Since those communications are encrypted, the mechanisms we have discussed do not work. However, researchers found out that the GFW has implemented a probing mechanism to identify suspicious activities. It pretends to be a client and tries to establish connections with servers. If a server responds with a black-listed protocol, the GFW can implement blockage to this server.

As a technology that is backed by the Chinese government, the GFW has ample resources to evolute to be a more sophisticated blocking mechanism. It will be a big obstacle to internet access from China in a foreseeable future.

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6. Summary

Internet access should be and has been recognized as a basic human right. However, more than half of the population around the world does not have internet access. GAIA, a sub-group of IETF is dedicated to the related research of the global access to the Internet for all. They were many previous attempts at this problem. Project Loon and internet.org are some of the centralized approaches led by companies. Decentralized approaches like guifi.net are also promising.

Lots of solutions are also proposed by researchers. The approximate network is a network infrastructure guideline that emphasizes the trade-off between cost and quality. The frugal 5G infrastructure tries to utilize emerging technology like the 5G network to cover rural areas' internet access. The existence of the Great Firewall of China needs more attention because it essentially blocks a large portion of the users from freely accessing the internet.

Global access to the Internet for all is an ambitious and yet necessary goal. It has its challenges, both coming from human and non-human factors. But we are on our way and we will keep trying because internet access is a basic human right.

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7. List of Acronyms

BGP	Boarder Gateway Protocol
CPR	Common Pool Resource
DNS	Domain Name System
GAIA	Global Access to the Internet for All
GFW	The Great Firewall of China
IETF	Internet Engineering Task Force
IRTF	Internet Research Task Force
ISP	Internet Service Provider
LTE	Long-Term Evolution
OSPF	Open Shortest Path First
P2P	Peer-to-peer
PoP	Point of Presence
RFC	Request For Comments
WLAN	Wireless Local-area Network

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