Internet Architecture: Current Limitations Leading towards Future Internet Architecture

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I. INTRODUCTION

The original internet (ARPAnet) architecture was, amongst other principles, fundamentally guided by the end-to-end principle in the early 1980s. This principle maintains that, a function should not be placed in the network if it can be placed at the end node correctly and completely (Saltzer et al, 1984). The result of this principle is an internet network core that is simple and provides general connectivity services. Papadimitriou et al (2012) defines design principles as the agreed structural and behavioral rules on how a designer can best structure the various architectural components. Ford et al (2009) describes design Principles as informal guidelines to help a protocol designer or network designer achieve a solution with desirable properties. Following this definition, internet design principle may be defined as the agreed fundamental rules guiding the structure and behavior of the internet architectural components at design time and at system running time.

The existing Internet architecture was founded based on some crucial design principles that rested within a list of goals, set in order of priority. Those design principles were pivotal to the success and exponential growth of the internet. Conversely, the priorities of the original internet designers do not match the needs of today actual users. As an example, network security, mobility and quality of services were not in the original list of requirements for the Internet. Security was added into the original Internet as an additional overlay instead of an inherent part of the Internet architecture. Today, the Internet has evolved from a U.S. military system prototype into an open, world-wide infrastructure. It has become more commercial and more oriented towards the consumer; presenting changing set of requirements emerging from users of the internet that compromises the original internet design principle and thus exposes issues and limitations that exists with the current internet architecture; hence the need for solutions that will accommodate the growing demand on the existing internet architecture.

This paper is focused on highlighting the current limitations of the existing internet architecture that is leading towards future internet architecture. Firstly, principles that informed the existing internet architecture design will be highlighted, followed by issues and limitations of the existing network architecture and the approaches towards the future internet architecture.

II. REVIEW OF RELATED WORKS

The primary goal for the Internet architecture was to develop an effective technique for multiplexing. From this assumption comes the fundamental structure of the Internet: a packet switched communications facility in which a number of distinguishable networks are connected together using packet communications processors called gateways which implement a store and forward packet forwarding algorithm. Packet switching was implemented as a fundamental component of the Internet architecture over Circuit switching because packet switching easily supports remote login, and the networks which were to be integrated together in the original internet project were packet switching networks.

The other goals which were established for the Internet architecture in order of priority states that: Internet communication must continue despite loss of networks or gateways; the Internet must support multiple types of communications service; the Internet architecture must accommodate a variety of networks; the Internet architecture must permit distributed management of its resources; the Internet architecture must be cost effective; the Internet architecture must permit host attachment with a low level of effort; the resources used in the internet architecture must be accountable.

According to Clark (2000) emerging requirements for the Internet of today includes: operation in an untrustworthy world, more demanding applications, ISP service differentiation and rise of third-party involvement. He also added that there are requirements in today's communication required to be handled for the internet architecture of the future. They include: situations where users communicate but don't totally trust each other; users communicate but desire anonymity; end parties do not trust their own software and hardware; and third parties assert their right to be included in certain sorts of transactions. Rise in new players, erosion of trust and rights, and responsibilities is pushing the internet to a new dimension. In a research by Ford et al (2009), socio-economic aspects are not intrinsic to the current Internet architecture. Today's architecture is becoming stressed as stakeholders introduce "hacks" to try to impose their economic desires on others, leading to a "tussle" of conflicting interests. Hence future internet design principle must integrate both technical and socio-economic aspects, so as to enable seamless adaption to changes in society's demands on the Internet as they occur, without requiring permanent redesign.

Research has taken two dimensions in the quest to fix the limitations with the current internet: clean-slate and evolutionary approach. Rexford and Dovrolis (2010) puts it this way: evolutionary Internet research aim to understand the behavior of the current Internet, identify existing or emerging problems, and resolve them under two major constraints: first, backward compatibility (interoperate smoothly with the legacy Internet architecture), and second, incremental deployment (a new protocol or technology should be beneficial to its early adopters even if it is not globally deployed). On the other hand, clean-slate research aims to design a new "Future Internet" architecture that is significantly better (in terms of performance, security, resilience, and other properties) than the current Internet without being constrained by the current Internet architecture.

III. EXISTING INTERNET PRINCIPLES, ARCHITECTURE AND LIMITATIONS

First, we consider some of the most important internet design principles that govern current internet connectivity. Understanding these ideas can help one appreciate why the internet is so popular as well as why it presents limitations.

3.1 Design Principles

i. *Heterogeneity support principle* (Saltzer et al, 1984): A heterogeneous network is made up of interconnected nodes and links of various types. Heterogeneity is unavoidable, and it must be accommodated by design. It implies the interconnecting of many existing network while hiding the underlying technology from the applications

ii. *Scalability*: Scalability states that "All designs must scale readily to very many nodes per site and to many millions of sites". (Saltzer et al, 1984).

iii. *Robustness principle* (Postel, 1981): the robustness principle as formulated according to the Postel Law which states: "be conservative in what you do, be liberal in what you accept from others", emphasizes that each protocol implementation must work with others as created by different individuals. This principle seeks to maximize interoperability among protocol implementations.

iv. *Adaptability principle*: Adaptability according to Braden (1989) "It is advisable to believe that the network is full of malicious entities who will send in packets designed to have the worst possible effect," he recommends. This assumption will lead to appropriate protective design...", and protocols will become more robust as a result.

v. *Modularization and Layering principle*: divides communication functionality into distinct modules with well-defined interfaces. Each of these modules corresponds to a functional assignment that provides a variety of behavioral and structural benefits, such as reduced complexity, isolation, and module reusability. Modularization, on the other hand, obstructs overall system optimization because each module/layer must be optimized separately.

vi. *Unambiguous addressing principle*: following the heterogeneous principle, the top layer Internet protocols must be able to identify end-points clearly and be independent of the hardware medium and hardware addressing. It enables the Internet to serve as a simple means of connecting fundamentally disparate systems.

vii. *Loose Coupling principle*: Coupling is the degree to which each architectural module relies on each one of the other modules (Stevens et al 1974). A loosely coupled system is one in which each of its components knows little or nothing about the definitions of other separate components and depend on each other to the least extent practicable. Loose coupling was implemented in the communication stack in the decoupling between applicative layers and the TCP/IP protocol.

viii. *The "end-to-end" principle*: End-to-end is one of the fundamental principles on which the Internet has been structured and built, as it guides the functional placement and the spatial distribution of functions across the layers of the communication stack (Saltzer et al, 1984). According to this principle, a function should not be placed in the network if it can be placed at the end node, while the network's core should provide a general connectivity service. When this principle is followed, it results in a network that is transparent to host application communication.

ix. *Simplicity principle*: Adding functionality or improving performance should not come at the detriment of increasing complexity. For instance, when designing or implementing protocols and intermediate systems, choose the simplest solution (Saltzer et al, 1984).

Papadimitriou et al (2012) recommends that there are design principles that should be preserved and applied to the future architecture of the Internet while others should be adapted or augmented. Heterogeneity, Scalability, robustness should remain and be even enforced while the others can be subject to revision or augmentation.

3.2 Internet Architecture

The existing internet is a network of networks that is packet-switched based on Internet Protocol (IP).

3.2.1 The Narrow Waist Architecture

The design goal of interconnecting many existing networks while hiding the underlying technology from the applications was achieved by the concept of *narrow waist*. The existing Internet has been described as having a narrow waist architecture because it has one universal protocol (Internet protocol) in the middle and several transport and application protocols above it, as well as the ability to function on top of multiple network technologies below it. In other words, the internet architecture has many protocols layered on top of each other with the Internet protocol (IP) in the middle, existing in the network layer. Hence, the concept of narrow waist. This implies that every internet device must understand the internet protocol (IP) to connect to the internet.

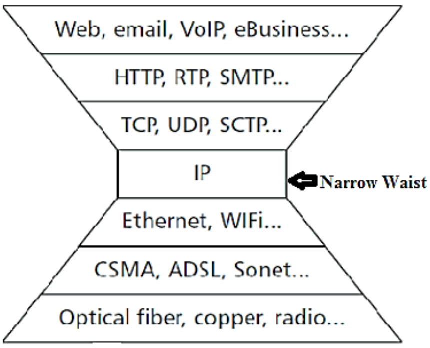

Fig. 1: Narrow Waist Architecture of the internet

3.2.2 Packet Switched Network

A Packet switched network, of which the existing internet is, is a digital networking communications technology that divides all transmitted data, independent of content, kind, or structure, into appropriately sized chunks called *packets*. The network layer, same layer as the narrow-waist, is designed as a packet-switched network. Packets are switched via connectionless mode or connection mode. With Connectionless mode, the internet provides unreliable, best-effort packet delivery. The service is connectionless because packets can be delivered without any prior end-to-end connection setup phase. As a result, performance is unreliable as packets may be lost, replicated, delayed, delivered out of sync and provides no predictable throughput. Hence, a best-effort delivery. Whereas, connection-oriented services service is more dependable because a connection must first be established, followed by communication, data transmission, and connection release. Where packets are lost, sender can resend the information.

3.2.3 Network of Collaborating Networks

The existing internet is made up of subnets of heterogeneous networks and autonomous systems with independent operation domains. As a result, the Internet is known as a network of networks. Routers connect network devices of the Internet infrastructure, which is subdivided into a collection of autonomous systems managed by an Internet Service Provider (ISP). This is the design based on the heterogeneity and scalability principles.

3.3 Limitations of the Existing Internet

The limitations of the current internet stems from some of its design principles and the fact that today's Internet architecture, which was designed in the 1960s, is based on a host-to-host communication model.

i. The end-to-end principle assumed that the end-points were non-fraudulent. End-points cannot be trusted to behave as expected. Since the end points cannot be trusted, more mechanisms in the network core are required to enforce and prevent fraudulent end points from sending compromised packets (Clark, 2000).
ii. The internet design of a simple service model called *best effort delivery* makes no guarantee about the throughput that any particular application will achieve at any moment. While applications such as email, web-access and file transfers have performed with this kind of service, today's applications such as live audio and video streaming require more than *best effort delivery*.
iii. The current Internet Protocol (IP) was designed to create communications between a source and a destination that are identified by IP addresses. Today's Internet has changed from host-to-host communication to content distribution, mobility, and cloud-services.
iv. The Internet is experiencing a significant shift from PC-based computing to mobile computing. Mobility has become the key driver for the future Internet. The current Internet cannot accommodate the rapidly increasing number of mobile devices. The

architecture cannot satisfy the demand of mobile network users. Ding et al (2016) assert that there exist a few problems: the Internet cannot resume download when device moves; the current network is fragile in mobile and wireless network; additional infrastructure is needed to support seamless mobility.

v. Many ad hoc patches have been created to fix the security vulnerabilities of the current networks which has led to unexpected consequences (Ding et al, 2016). Moreover, it has become extremely difficult to support the ever-increasing demands for security, performance reliability, social content distribution, mobility, and so on through such incremental ad hoc patches on top of the existing architecture (Pan et al, 2011).

IV. APPROACHES FOR THE FUTURE INTERNET ARCHITECTURE

Given the emerging problems of today's Internet, many new Internet architectures have been proposed by the networking community. This section presents clean-slates approaches to the future internet architecture. It by no means represents the exhaustive list of clean-slate future internet architectures.

4.1 Content-Centric Internet Architecture

The Internet as a packet-switched network, creates a communication channel between the source and destination nodes, which may be separated by one or more hops, to accomplish secure communication. In this case, efforts are concentrated on securing the channel rather than the packets itself. These fundamental operations have been the backbone of the Internet's expansion for more than four decades. They do, however, have some flaws. There is just one type of data packet on the Internet: one that transports both content and requests for content between users; security features like encryption are not provided by default and security functions are achieved by introducing more protocols, which raises complexity on the network.

Content-centric internet Architecture takes a different approach. There are two sorts of packets in a Content-centric internet Architecture: content packets and interest packets. They collaborate to provide users with information. Content packets resemble regular data packets. A receiving end sends out an Interest packet with a name that specifies the required data. When the Interest reaches a node that has the requested data in its local storage, known as the Content Store, a data containing the requested name and data packet content, as well as a signature by the producer's key, is sent back. Content-centric internet Architecture has a forwarding engine made up of three components: the content store, the pending interest table, and the forwarding information base. The engine employs algorithms to identify which content to retain, or cache, for the future, and how best to distribute content to users while routing information.

Content-centric internet Architecture retains the narrow waist IP architecture, with some revisions and augmentation. Worthy of note is that it replaces IP packets with content chucks. This approach improves on our existing Internet protocols by permitting any node to copy and store content anywhere in the network. This implies that content is not restricted to the originating server but can move throughout the network and be stored in places where it is most needed. This approach will improve data delivery. A Content-centric internet network can be more flexible and responsive than today's networks by focusing on the location of content rather than tracking down the address of its originating host. Indeed, studies have indicated that, the Content-centric internet model will outperform today's IP-based networks in three critical areas: dependability, scalability, and security (Yu & Gu, 2011).

As a result of Content-centric approach, some future internet architectures have emerged: Named Data Networking (NDN) and Content Aware Searching Retrieval and Stream (COAST). NDN addresses the Internet's current communication architecture's flaws and accommodate developing communication patterns, shifting the focus from where the host is to what the content is. COAST goal is improving content discovery and delivery. It also aims to develop a content-centric network architecture capable of intelligently and efficiently connecting billions of content providers with billions of content users, as well as providing quick content-aware retrieval, distribution, and streaming.

4.2 Mobility-Centric Internet Architecture

Mobility refers to the ability to accommodate mobile and wireless devices in a seamless manner as the norm rather than an add-on. The current internet architecture was created mostly with static hosts in mind. This is evident in the nature of the Internet's addressing structure, name resolution service, and assumptions about end-to-end connectivity. In the last few years, mobile devices and apps have exploded in popularity, and mobile Internet traffic is on track to surpass wired Internet traffic in a few years. Despite the fact that the Internet has made remarkable progress in accommodating the growth of mobile devices, its legacy architecture remains a fixed wired internet and thus, suffers some shortcomings that fails to address the trend of dramatically increasing demands of mobile devices and services.

The fundamental design principle of mobile-centric internet architecture lies in the separation of endpoint identifiers from their addresses (i.e. network location). Current internet architecture combines both in the form of IP addresses, hence poorly supporting mobility (same identity, changing locations), multihoming (single identity, multiple locations), and security because IP addresses can be easily hijacked or spoofed.

MobilityFirst is a future Internet architecture with mobility and trustworthiness as central design goals. Mobility means that all endpoints – devices, services, content, and networks – should be able to frequently change network attachment points in a seamless manner (Venkataramani et al., 2014). According to Venkataramani et al (2014) MobilityFirst is driven by two critical high-level design goals: seamless mobility and trustworthiness, i.e., seamless mobility is the ability for devices, services, and content to communicate in a location-independent manner, and trustworthiness, is the assurance of security and privacy properties despite malicious behavior on part of a small fraction of endpoint or network nodes.

4.3 Service-Oriented Internet Architecture

Service-Oriented network architecture is founded on the bases that internet users' desire services, not channels for packet forwarding, hence, the Internet should be viewed and structured as a service pool rather than a channel for packet forwarding. The Internet is a collection of services for data transport, processing and storage. Xie et al (2011) puts forward that with Service-Oriented internet architecture, applications will be service-aware and will naturally accommodates mobility of mobile devices as devices only change their access points but not their services. Service-Oriented internet architecture facilitates security at the service level, since interfaces between users and the Internet will focus on service requests and service responses; and finally, this architecture facilitates the integration of the cloud computing infrastructure into the Internet.

Service-Oriented Future Internet Architecture (SOFIA) is a Service-Oriented internet architecture.

SOFIA adds a service layer to the protocol stack, with new methods including service migration, service label/location separation, and service authentication. SOFIA retains the narrow waist IP architecture, with some revisions; it replaces IP with a code for specific services called *global unified service ID*. In addition, another label called *locator* is utilized to specify the location of the network node, thus realizing the separation of service identity and service location.

V. DISCUSSION

The challenge in designing a clean-slate future internet architecture, as opposed to the evolutionary approach, is that the former must anticipate all possible emergence of unanticipated applications. Secondly, any future internet, while improving on existing limitations, must preserve those design goals and principles that makes the existing internet scalable, heterogeneous, robust and extensible. Thirdly, with many possible approaches to the future internet architecture, a key emerging issue is how to select which one of these approaches holistically addresses the limitations of the existing internet architecture as to become the future internet choice.

It is apparent that handling several issues in a single architectural design seems a difficult problem than anticipated. Although these different approaches have different emphases, and is beneficial to tackling the limitations by piecemeal approach, however, an integration of theses architectures to form a unified internet architecture will be practical approach that will have real impact capable of replacing the existing internet.

VI. CONCLUSION

This paper presents a discourse on the limitations of the existing internet architecture and various proposed approaches towards future Internet architectures. It is not meant to be a complete enumeration of all approaches but a highlight of the likely directions, the internet of the future will take.

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