Internet of Things Communication Reference Model and Traffic Engineer System (TES)

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Abstract. One of the biggest challenges facing *Internet of Things (IoT)* is the existing infrastructure of Internet and its mechanism of action. This paper proposes a new system, which sends the *full* Internet best path (between source and destination objects) to source object on IoT. This will help data of source object to reach its final destination object faster. This system saves most of re-calculation of the Internet best paths again and again in the Internet Routers during a data trip. The authors call this system *Traffic Engineer System (TES).* The most important effect of this system is that it changes the form of "*Internet of Things Communication Reference Model*". This paper merges two addressing layers (IP/ID and Link) from this model in one new layer; where routers transition data through one address and the data have its full best path.

Keywords: Internet of Things (IoT), IoT Communication Reference Model, Traffic Engineer System (TES).

1 Introduction

Internet of the future is likely to be dramatically different from the Internet we use today. This development is opening up huge opportunities for each of the scientific research and the economy. However, it also involves risks and undoubtedly represents an immense technical and scientifically challenge [1]. The Internet Protocol (IP) is suited for networking devices with stringent requirements [2]. According to Internet of the future concepts, *data will be self-addressable and self-routable* [3]. In the world of Internet of Things (IoT), can we use IP as the data exchange protocol directly without any modifications with urgent need for more efficiency? Especially with this tremendous progress in communication techniques and the power of hardware. The ability to uniquely identify things (objects) is critical for the success of IoT. This will not only allow us to uniquely identify billions of devices, but also to control remote devices through the Internet [4]. On the other hand in IoT, routing packets and inter-nodal communication have received little attention; mainly due to the sheer reliance on the today's Internet as it is and as a backbone [5]. IBM's newest study reveals how new technologies support the development of the Internet of Things, and how the Internet of Things provides the foundational infrastructure for a smarter planet [6].

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1.1 Previous Work

This paper represents a supplement to authors' previous paper [7] related to the communication between objects in Internet of Things (IoT). Figure 1 illustrates the output model "IoT Communication Reference Model" in that paper. The model is built from 7 layers, bottom to top, in the following order: Physical, Quality of Service, Security, Link, IP/ID, End-to-End, and Data; where two new layers have been added to the original model (Security and Quality of Service). *This paper merges other two layers from the model in one new layer!*

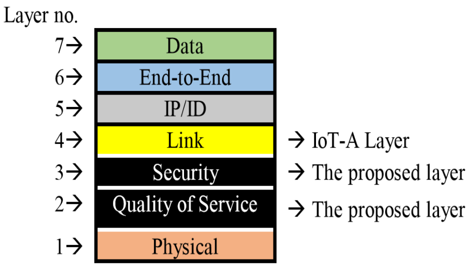

Fig. 1. IoT Communication Reference Model

1.2 Addressing in the Model

Why does today's Internet require two types of addresses (like IPv4 and MAC) to achieve the process of communication between source and destination objects? And then transfer data between these objects through the Internet communication devices (Routers). *In the beginning,* we all agree that the issue of "*Addressing*" as it is now is a successful design that has been implemented and has achieved the communication goals. However, that does not mean this is the only way! There may be other more efficient ways, especially since we are on the verge of a big changes in everything through IoT. This leads us to think about everything related to today's Internet. *Secondly*, to answer this question we need to know a detailed and profound answer to the following question: what is the job and benefits of IPv4 and MAC Addresses? Also, because this paper wants to develop "IoT Communication Reference Model", it has to find the relation between these addresses, model's layers, and Internet devices. *Finally*, note that authors use IPv4 and MAC for simplicity the idea and as a guide for what they need to prove (although authors know that the Internet of Things is more complicated than that). For example, nowadays we are going to transition to a new generation of IP addresses (IPv6) [8]. As well as with respect to the enormous diversity in addressing when adding various and highly heterogeneous objects to the Internet to build IoT. At the end of this paper it will become clear how the authors implement this idea with IPv6 and new parallel addresses to MAC.

Table 1 shows a comparison between MAC and IPv4 Addresses [9, 10, 11, and 12] and contains the answer to all previous questions. IPv4 is an address for location and carries in data packet to help routing table in Routers to route the data to its final destination; Communication Address from End-to-End. MAC is a name for hardware and carries in data frame to help CAM table in Switches to forward the data to the next neighbor on the track; Connection Address for Hop-by-Hop.

So we cannot make Internet work without one of these addresses, because each address has its characteristics, advantages, specific role, and final goal. *However, it is possible to change its mechanism of action!*

Table 1. Comparison between IPv4 address and MAC address

VS \ Addressing	IPv4	MAC
1. Name	**I**nternet **P**rotocol	**M**edia **A**ccess **C**ontrol
2. Addressing	It's address for location	It is more comparable to a name than an address
3. Assigned by	Network administrator or Internet Service Provider	During manufacturing the Network card
4. Nature	Logical Address	Physical Address
5. Static/Dynamic	Static/Dynamic and could be changed	Static and Permanent and could not be changed
6. Unique	Unique; relation to the time or provider	Unique; relation to the hardware
7. Location	Intranet/Internet - Per Card	LAN/Link - Per Card
8. Size	32 bit (4 Byte)	48 bit (6 Byte)
9. Notation	Dotted Binary/Decimal	Columned Hexadecimal
10. Formula	Network ID + Host ID (As needed)	Manufactory ID + Card ID (fifty-fifty)
11. Types	Class A,B, and C - Private and Public	Accordingly manufacturers classification
12. Datagram	Packet carry First Source's IP and Final Destination's IP	Frame carry neighborly relationship Source MAC and Destination MAC
13. Goals	Communication Address from End-to-End somewhat resembles Passport number in our life	Connection Address for Hop-by-Hop somewhat resembles the local ID in our life.
14. Using for	Routing Packets by Routing Tables	Forwarding Frames by CAM Tables (MAC Tables)
15. IoT CRM Layer	5^{th} IP/ID Layer	4^{th} Link Layer
16. Devices	Layer 3 Devices; like Router	Layer 2 Devices; like Switch
17. Tables	Routing Table support around 370,000 Network	CAM or MAC Table support around 8000 MAC
18. General broadcast	255.255.255.255	ff:ff:ff:ff:ff:ff
19. Translation	DNS: URL or Name → IP Address	ARP: IP Address → MAC Address
20. Source	IANA	IEEE

1.3 Imaginary Simulation Scenario

An imaginary simulated scenario to simplify the problem is introduced: Suppose that there are two persons on a trip in a country for the first time. The first person has a map for this country while the second has no map. Therefore, if we assume that they will go to the same destination, who will be the faster? Definitely the first one, because the second will lose some time by asking people about the destination. The current situation today when data transition in Internet to its destination, it represents the other person: asking each Router during the trip about the best path to the destination. Note: Persons represent the Data, Destination represents destination object IP address, Map represents the Best path, and People represent Routers.

The remaining part of this paper is organized as follows: Section 2: discusses the issue of best path to the final destination with latest mechanisms and its problems from our point of view. Section 3: our proposed system "Traffic Engineer System". Section 4: results and discussions. Section 5: conclusions and future work. Section 6: acknowledgments.

2 Best Path for Final Destination

With the rapid growth of the Internet and the establishment of IP as the Layer 3 protocol of choice in most environments, the drawbacks of traditional IP routing became more and more obvious [13]. One of these drawbacks is re-calculation of the Internet best paths to final destination again and again in the Internet Routers during data trip. In recent years, there have been several attempts to reduce the repetition of this process, improve its performance, and accelerate it. The best and most powerful of those attempts is Cisco Express Forwarding (CEF) from Cisco, Multiprotocol Label Switching (MPLS), and Traffic Engineer mechanism.

2.1 Cisco Express Forwarding (CEF)

The basic function of a router is to move packets through the Internet. For a router to forward packets, it needs to look up the destination IP address of the packet in a Routing Table and decide which route to use to switch the packet by using ARP Table [14]. Cisco developed Cisco Express Forwarding (CEF) for its line of routers, offering high-performance packet forwarding through the use of dynamic lookup tables. A CEF-based multilayer switch (switch/router) consists of two basic functional blocks. 1) The Layer 3 Engine is involved in building routing information (Routing Table and ARP Table). 2) The Layer 3 Forwarding Engine can be used to switch packets in hardware (Forwarding Information Base FIB and Adjacency Table). Forwarding Information Base (FIB) contains routing or forwarding information and the next-hop address for each entry. Adjacency Table consists of the MAC addresses of nodes that can be reached in a single Layer 2 next-hop. *In brief*: “CEF means route once from FIB and switches many in hardware”. At times, however, a packet cannot be switched in hardware, according to the FIB [15]. As a result, there is still a question and search for the best path for one-time in each session between the source (sender) and the destination (receiver) objects; which means that the process occurs only for one-time in Router. However, it is still repeated in all Routers from the Internet and along the trip until the data reaches its final destination. Figure 2 illustrates this issue and the time it takes to repeat this process.

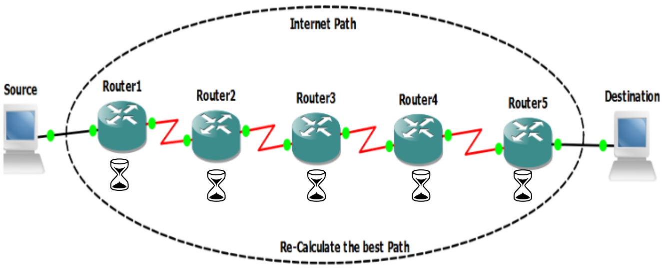

Fig. 2. Re-Calculate the Best Path on Routers

2.2 Multi-Protocol Label Switching (MPLS)

Multiprotocol Label Switching (MPLS) has been around for several years. It is a popular networking technology that advertises labels attached to IP packets between routers to forward the packets across the Internet. Where routers build a label-to-label mapping so forward the traffic by looking at the label and not the destination IP address. MPLS is a great benefit to the service providers that deploy it and to their customers, because one of the reasons for a label-swapping protocol is the need for speed [14]. MPLS was created to combine the benefits of connectionless Layer 3 routing and forwarding with connection oriented Layer 2 forwarding [13].

2.3 Traffic Engineer

With IoT the delivery of Internet communications services has become very competitive and end-users are demanding very high quality service from their service providers. Consequently, performance optimization of large scale IP networks, especially Internet backbones, has become an important problem [16]. Traffic engineering (TE), or the ability to steer traffic through the Internet, is to get the traffic from edge to edge in the Internet in the most optimal way. For example, TE can bring a solution by steering the traffic or a portion of it away from the overloaded links, because the forwarding paradigm of IP is based on Routing Protocol mechanisms, which is least-cost path forwarding (best path). The IP forwarding paradigm does not take into account the available bandwidth capacity of the link, which might differ significantly from the cost that is assigned to the link [14].

2.4 Lessons Learned

It is noticeable that all these genius solutions are not exposed to the root of the problem! These solutions are made from the perspective of the devices themselves or a service provider not from the infrastructure of the Internet as a whole. The problem is to re-calculate the Internet best paths to final destination again and again in the Internet Routers during a data trip. This leads to excess consumption of the processor, memory and time in Internet devices. *The only benefit of a repetition of this process is to select the best path in an accurate way, which can be achieved without re-calculate this process.* This paper attempts to prevent the process of re-calculation of the best path using the proposed "Traffic Engineer System" (see Figure 2).

3 Traffic Engineer System

There is a massive growth of the Internet towards the Internet of Things. As a result of this, there are an enormous diversity and tremendous increase will happen in objects *Addressing*. We need a system able to help source object data to reach its final destination through these addresses. Where calculating and determining the full best path depends on final destination address. But for one-time in Routers along the trip to save time and thereby increases the speed. *Traffic Engineer System TES* will perform this function on Internet of Things. Like other TCP/IP-based services, TES is a protocol that works on servers. These servers maybe in 1) Internet Routers, 2) DNS servers (As additional service to DNS), or 3) *NEW* servers. This paper prefers the third option and will work to create it; this paper is the first step. The idea of working for this system is derived from some of the systems and protocols, such as: Domain Name Services (DNS) as a system and Open Shortest Path First (OSPF) as a protocol [9, 10, 17, and 18].

3.1 TES Server

TES server provides the source object with the full Internet best path to final destination; instead of the source's data continues to ask Internet Routers repeatedly along the trip about it. Thus, the objects should have the TES server IP like DNS server IP.

1) The source object sends a unicast query containing the IP for destination object to a TES server.
2) The source object eventually receives a reply, which includes the full best path for the destination object through the internet.

Source object can then arrive to the destination faster; where transition will be with one address and switch all the time in hardware.

Since the best paths to all possible Internet final destinations are huge and a single server might not hold all these paths. As a result, there is a good suggestion that the source object's TES server (*Nearest* server) asks another TES server. At most calculated that process twice; the first at the TES Nearest server and the second at the *Service Provider* TES server. Please see Figure 3. We conclude from this that TES adds an additional delay -sometimes substantial- to the Internet applications that use it. Fortunately, it is possible to *cache* the desired best paths in TES Nearest server, which helps to reduce TES network traffic as well as the average TES delay. Also, it is possible to use a *local cache* for the best path in IoT objects themselves for 6 minutes for example; to get rid of TES-requests to any TES server as well as to get rid of TES reply time.

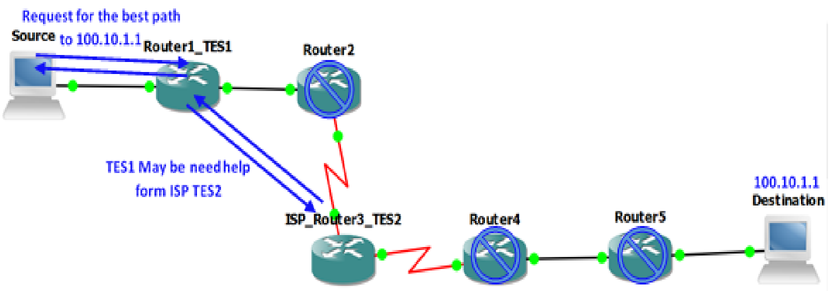

Fig. 3. Traffic Engineer System Servers

3.2 Database of Topology

TES aims to find the full best path to any destination in the Internet. In operation, each TES server sends an Internet network design (topology) to other servers on the Internet to build its database. After that database is constructed, the server filters the database to the best paths only. The *Best-Path* table is populated with these resulting best paths per destinations in the Internet. From this table, TES servers respond to the query from source objects and give it the full best path for its data to travel to the final destination. In case of any changes in the Internet network TES servers update its databases and then the Best-Path table. TES servers for sure require more processor power, memory size, and high bandwidth, which is easy nowadays with the tremendous progress in Internet bandwidth and the hardware industry.

3.3 TES Best Path Format and Some Facts

This section represents the biggest challenges this paper faces and will help us to overcome them. The small size of the Maximum Transfer Unit MTU in Internet, which equals 1500 bytes, may represent a significant impediment to TES. TES may cause an increase in MTU size if it is designed freely. This paper did not want to change the MTU in this paper to demonstrate the principle feasibility of the idea at first, although there is tremendous progress in bandwidth and the hardware industry making it possible.

Firstly, we need to determine the size of the additions that are added by Link and IP/ID layers to know the available size to design the "best path" additions. Do we need to change this or not? The maximum size of additions in bytes (header and tail) of the link layer service provided by Ethernet to packet to build the frame is 38 bytes [20]. The maximum size of additions in bytes (header) of the IP/ID layer service provided by IPv4 to segment to build the packet is 60 bytes [11].

Secondly, we have an old technique that can help us understand what this paper wants to do in depth, which is *Source Routing*. In IP packet header options, source routing allows a sender of a packet to partially or completely specify the route the packet takes through the network. There are restrictions on a lot of Internet devices that do not support this feature for security reasons, but this issue was solved in the previous paper with Security Layer in IoT Communication Reference Model [7]. For example: Loose source routing option, in which a series of IP addresses for router interfaces is listed (up to nine addresses). The packet must pass through each of these addresses, although multiple hops may be taken between the addresses. This means that each router, instead of examining the destination IP in traveling packet and choose the next hop to forward the packet to, in source routing, the source takes some or all of these decisions by itself. This way, it removes the decision-making from the routers and puts it into the hands of the users [11, 20, 21, and 22].

Thirdly, the average AS-hops between any source and any destination in the Internet is 3 or just a bit above 3 and the maximum is around 13. The most frequent total Router-hops is less than 15 hops and the largest distance and worst case in total Router-hops is between 25 and 30 hops in over 95% of all possible traffic through the Internet [23].

4 Results and Discussions

4.1 New Frame Format

This paper will add the full best path to final destination instead of the source and destination IP addresses to data segment. However, unlike Source Routing, it will add a series of IP addresses for Routers themselves (Router ID) to represent the full best path. It chooses Router ID to make it easy to routers to select appropriate link to its neighbors. The series consists of 15 IP addresses as a maximum, because we have 60 bytes for this; where: {15 Router * 4 bytes IP address = 60 bytes} and the most frequent total Router-hops in Internet is less than 15 hops. However, what will happen if total Router-hops are more than 15? Furthermore, there is a good suggestion that the source object's data requests the rest of full best path again from the last TES server/router (*Transit* server), where it stopped due to depletion of the IP addresses series. Therefore, it must retain destination address in frame header. At most calculated that process twice; the first at the *Nearest* TES server and the second at the *Transit* TES server. Figure 4. Illustrates the new data frame format.

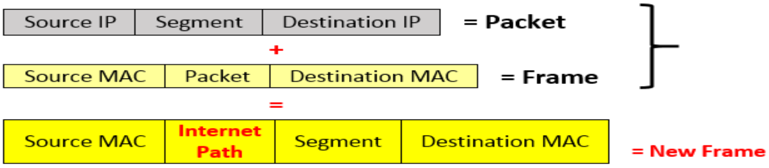

Fig. 4. New Data Frame Format

Thus in the worst case with TES, the question about the full best path will be repeated for only three times in Nearest, Service Provider, and Transit TES servers. In the perfect case, Data will be directed to their final destination without any question when we use a local cache in IoT objects.

All we need in the near future is to study the implementation of the idea of TES with all kinds of addresses in IoT, whether with IPv6 or other addresses of IoT objects. In fact, there is a simple solution to this issue. Like MPLS, routers can keep working with IPv4 in partial of Router's IDs and IPv6 for IoT objects. Thus, when any object in IoT wants to communicate with another object, the full best path will be written in IPv4 (series of Routers IDs).

4.2 IoT Communication Reference Model

Now we are getting to the most important results of this paper and TES, which is its impact on IoT Communication Reference Model. *Based on the fact that routers transition data through one address and the data have its full best path, this paper merges two addresses layers from the model in one new layer*. Figure 5 illustrates the new model with new proposed layer *Addressing Layer,* which will replace the two layers IP/ID and Link. The IoT Communication Reference Model is built, bottom to top, in the following order: Physical, Quality of Service, Security, *Addressing*, End-to-End, and Data.

The new layer: Addressing layer is classified as Layer 4. The major function of *Addressing* layer is to provide objects in IoT with the full best path to their final destination.

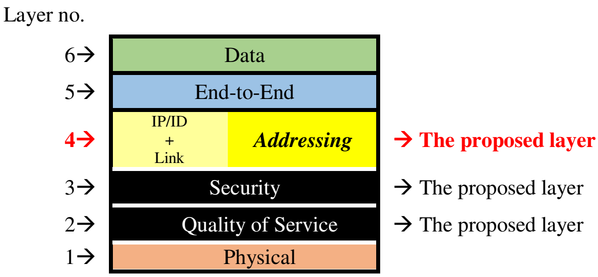

Fig. 5. New IoT Communication Reference Model

5 Conclusions

IoT will achieve '6A connectivity' (i.e., any time, any one, any thing, any place, any service, and any network) eventually as the vision of ITU and European project cluster (CERP-IoT). Building this infrastructure of any NETWORK remains the biggest challenge for driving future ubiquitous and pervasive computing [24]. The Traffic Engineer System (TES) is the proposed solution to this challenge. TES is a distributed database implemented in a hierarchy of TES servers and TCP/IP protocol that allows source objects in IoT to query the full best path for specific destination objects. With TES Source object can arrive to the destination faster; although transition will be with one address and switch all the time in hardware. In the worst case with TES, the question about the full best path will be repeated for only three times in Nearest, Service Provider, and Transit TES servers. In the perfect case, Data will be directed to their final destination without any question when it uses a local cache in IoT objects.

In the end as authors to this paper, we should recognize that there is a great challenge facing this paper. This paper requires a lot of changes and testing at the level of today's operating systems and devices in addition to creating a new system (TES), which requires support of one sponsors at implementation stage as a project and a specialized team work in many disciplines of Information Technology.

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