STORAGE PATH OPTIMIZATION FOR IOT

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Preface

Internet of Things (IoT), a hot topic for research and industry, integrates billions of devices in many industry domains with different platforms, applications, and functions using one network. Cloud computing is the backend of IoT processing and storage. In this Knowledge Sharing article, we propose a new idea about the device registration approach and Storage Path Optimization (SPO) in IoT to minimize upload time using smart storage array controllers. Testing results for the proposed techniques minimize upload time in an IoT network compared with traditional data upload techniques that depend on sending data from the sender device to the receiver device. We envision there will be more than 50 billion connected devices by 2020. We call this the 3rd Generation Internet and it will fundamentally change the way we innovate, collaborate, produce, govern, and achieve sustainability. We believe that will be crucial in the IoT world.

Overview

IoT is a global inter-connection for devices, objects, and things that contain embedded technologies to sense, communicate, and interact [1]. It is a key enabler for many emerging and future “smart” applications and technology shifts in various technology markets. This ranges from the connected consumer to smart homes and buildings, e-health, smart grids, next generation manufacturing, and smart cities [2]. IoT is predicted to become one of the most significant drivers of growth in these markets; as shown in Fig. 1.

In 2020, there is an expectation to have 12 billion Mobile Connected Devices [4], 24 billion Wired Connected Devices [4], 30 billion Wireless Devices [5], 30.1 billion Autonomous Things [6] and 50 billion Overall Connected Devices [7]. With these huge numbers of devices/things, IoT becomes more promising and challenging. Because billions of things will have an IP address and connect to a network, IoT aggregates many domains in one network such as the medical industry, automotive, public sector, consumer devices, transportation, and so on. Fig. 2 shows the main sector that will make use of IoT network by their things [8].

In this article we will share our experiment based on lab exercises and real world scenarios that can be applied widely and consumed by major IT firms, including social media giants.
IoT facilitates dynamic control of industry and daily life, improves the resource utilization ratio, and enhances the relationship between humans and nature.

The high tech market will grow by enabling IoT cross-domain interaction and platform unification through increased system compatibility, interoperability, and functional exchangeability utilizing open source community as well. Currently this is what is being adopted widely by many IT giants. Contributing in many standards organizations to define an IoT architecture framework that covers the architectural needs of the various IoT Application Domains will increase transparency of IoT system architectures to support system benchmarking, safety, and security assessments and expand market growth in this new era.

![Figure 1: Gartner Hyper Report 2014](image-url)
Figure 2 IoT Application Domains & Stakeholders

Figure 3: IoT Drivers

Source: * GSMA, ** ABI Research, *** IDC and **** Cisco
**Problem Statement**

First, we need to define one of the problems that we face currently in this era of IoT.

The Internet is the bottleneck in data upload/download in IoT, increasing upload, delaying download, and degrading network performance.

Current approaches depend heavily on the Internet with redundant uploads and downloads. The available cloud platforms are not IoT-aware which implies a separation between the networking and storage methodologies.

**Problem 1**

Dependence on the Internet with billions of devices is a challenge in IoT that may lead to a bottleneck.

**Problem 2**

Upload delay in IoT network from the sender to IoT cloud provider network and from IoT cloud provider to the receiver; including redundant upload/download for the same content.

**Problem 3**

Storage back-end in cloud computing is not IoT-aware and thus does not optimize data handling to enhance IoT cloud performance.

**Our approach**

Our objective in this article is to minimize the dependency on the Internet in data upload in IoT, which minimizes the upload delay. We also strive to make the storage arrays’ controller IoT network-aware, such that devices of the same user or of the same application have accordingly specific VM and storage allocation that optimizes the overall performance.

**Novel Aspect 1**

**IoT Users/Devices Clustering:** We propose the following flowchart in Fig. 1 for IoT users and devices clustering, assignment to virtual machines, and storage allocation.
Fig. 4 shows an example for VM and storage allocation.

**Figure 4: IoT Users/Devices Registration**

**Figure 5: Example of Cluster based User/device Resource Allocation**
**Novel Aspect 2**

**IoT Storage Path Optimization (IoT-SPO):** We propose the flowchart in Fig. 2 for IoT network behavior utilizing the SPO algorithm. It utilizes the SPO algorithm when trying to send large data sizes between IoT devices.

![Flowchart of IoT network flow with SPO](image)

*Figure 6: IoT network flow with SPO*

The SPO algorithm uses the source device ID, destination device ID, and storage allocation matrix from the IoT server to move the data between the source and destination LUNs without dependency on the Internet to move data.
Fig. 7 illustrates a flow chart explaining how SPO works:

The improvement achieved by SPO in the total delay increases with large data sizes being transferred in the IoT network.
Algorithm Illustration Example

The diagrams below show SPO algorithm in action. A sender device is sending one large file to another receiver device. For each case, we have a formula for the time calculation before and after applying SPO.

Before SPO

Figure 8 depicts the data path scenario without SPO algorithm.

Figure 8: Storage Path without SPO

- Time Calculation – without SPO
  - **Time to receive** = \( T_{DC} + T_{CA} \)
  - **Time to send** = \( T_{AC} + T_{CD} + T_{WLAN} \)

The time variables above are a function of the file size in the form:

\[
T = T_{fixed} + \text{Size}_F \times T_{transmission}
\]

Where:

- \( T_{fixed} \): any fixed time component like \( T_{propagation} + T_{processing} \), etc.
- \( T_{transmission} \): depends on the link speed
- \( \text{Size}_F \): the file size
Area of Optimization:

- Optimize on: \(\text{Size}_F\)
- Send small header over the network instead of the large file
- Large file stays in SAN and is uploaded per request
- Header size is: \(\text{Size}_H << \text{Size}_F\)

After SPO

Figure 9 and 10 depict the data path scenario without SPO algorithm for 1 receiver and \(N\) receivers.

**Figure 9:** Storage Path with SPO 2

**Figure 10:** Storage path with SPO
- Time Calculation – with SPO
  - **Time to send** = $T_{DC} + T_{CA} + T_{SAN}$
  - **Time to receive** = $T_{AC} + T_{CD}$

The time variables above are a function of the header size in the form:

$$T = T_{fixed} * Size_H * T_{transmission}$$

Where:

- $T_{fixed}$: same like before
- $T_{transmission}$: same like before
- $Size_H$: the header size (smaller than F_size)

- Benefits:
  - Less time between Device, cloud and Arrays as $Size_H << Size_F$
  - $T_{SAN}$ is $< T_{WLAN}$ as SAN is faster than WLAN and suited for sending large files
  - Time Improvement is proportional to $Size_F$ and number of receivers $N$

**Time improvement** = $[(T_{CA} + T_{DC}) * (Size_F - Size_H) + (T_{WLAN} - T_{SAN})] * (N-1)$

Where $N$ is the number of receivers
Performance Evaluation

**Testing Scenarios**

In this section, we test using the proposed SPO approach and compare it in terms of the upload delay (sec) with sending the data between IoT devices only, which is currently used. Matlab and lab model are built to simulate IoT network setup. For this comparison, the testing scenarios below are used:

- **Scenario0**: 1 sender, 1 receiver, 1 frame
- **Scenario1**: 1 sender, 1 receiver, N frames (TCP)
- **Scenario2**: 1 sender, 1 receiver, N frames (UDP)
- **Scenario3**: 1 sender, M receivers, N frames (TCP)
- **Scenario4**: 1 sender, M receivers, N frames (UDP)

For a detailed illustration of the tests implemented, we have established a time diagram for data sending in each of the above-mentioned testing scenarios.
For the IoT-SPO tests:

Scenario 0: (1 sender, 1 receiver, 1 frame)

Figure 11: Time Diagram of Scenario 0; (a) Before and (b) After SPO
Scenario 1: (1 sender, 1 receiver, N frames (TCP))

Figure 12: Time Diagram of Scenario 1; (a) Before and (b) After SPO
Scenario 2: (1 sender, 1 receiver, N frames (UDP))

Figure 13: Time Diagram of Scenario 2; (a) Before and (b) After SPO
Scenario 3: 1 sender, M receivers, N frames (TCP)

Figure 14: Time Diagram of Scenario 3; (a) Before and (b) After SPO
Scenario 4: 1 sender, M receivers, N frames (UDP)

Figure 15: Time Diagram of Scenario 4; (a) Before and (b) After SPO
When the above-mentioned testing scenarios were implemented, we assumed having the below testing environment:

- Using WLAN 802.11g/n
- 10 users share the WLAN AP
- IoT Server with Xeon Quad-Core Single Queue
- LUNs are with SAS Disks. 15k RPM with RAID 5 (4+1)

Below are the values

- $T_{\text{upload}} = T_{\text{Buffer-to-server}}$
- $T_{\text{WLAN}} = 0.6$ msec → From paper [9]
- $T_{\text{AP-to-Server}} = 41$ msec → From our testing
- $T_{\text{IOT-server}} = 0.004$ msec → From paper [10]
- $T_{\text{LUN_write}} = 11$ msec → From testing on VNX (Pool with SAS disks RAID 5 “4+1”)
- $T_{\text{read}} = 0.25 \cdot T_{\text{Write}}$ → Due to RAID 5 penalty
- $T_{\text{LUN_read}} = 3$ msec → From testing on VNX (Pool with SAS disks RAID 5 “4+1”)
- $T_{\text{Copy}} = T_{\text{LUN_write}} + T_{\text{LUN_read}}$
- $T_{\text{notification}} = (T_{\text{WLAN}} + T_{\text{AP-to-Server}} + T_{\text{IOT-server}}) \cdot 66/1526$
- $T_{\text{ack}} = T_{\text{AP-to-Server}} \cdot 66/1526$ → From Ethernet frame structure

**Testing Results**

Shown below are the results of the tests comparing the IoT-SPO and sending the data between IoT devices only:

**Total Delay for Scenario 0 for the techniques:**

- $T_{\text{TotalDelay-0 without}} = T_{\text{WLAN}} + T_{\text{AP-to-Server}} + T_{\text{server}} + T_{\text{LUN_write}} + T_{\text{LUN_read}} + T_{\text{Copy}} + T_{\text{notification}}$
- $T_{\text{TotalDelay-0 with}} = T_{\text{WLAN}} + T_{\text{AP-to-Server}} + T_{\text{server}} + T_{\text{LUN_write}} + T_{\text{Copy}} + T_{\text{Notification}}$
Total Delay for Scenario 1 for the techniques:

- \( \text{Total Delay}_{\text{Without IoT-SPO}} = T_{\text{Wlan}} + T_{\text{AP-to-Server}} + (N-1)T_{\text{AP-to-Server}} + N*T_{\text{ack}} + T_{\text{IOT-server}} + N*T_{\text{AP-to-Server}} + T_{\text{wlan}} + N*T_{\text{LUN-read}} \)

- \( \text{Total Delay}_{\text{With IoT-SPO}} = T_{\text{Wlan}} + T_{\text{AP-to-Server}} + (N-1)T_{\text{AP-to-Server}} + N*T_{\text{ack}} + T_{\text{IOT-server}} + T_{\text{LUN-write}} + N*T_{\text{Copy}} + T_{\text{notification}} \)
Total Delay for Scenario 2 for the techniques:

- \( \text{Total\_Delay\_2} \text{Without IoT-SPO} = T_{\text{Wlan}} + T_{\text{AP\_to\_Server}} + (N-1) * T_{\text{AP\_to\_Server}} + T_{\text{IOT\_server}} + T_{\text{LUN\_write}} + N * T_{\text{AP\_to\_Server}} + T_{\text{Wlan}} + N * T_{\text{LUN\_read}} \)

- \( \text{Total\_Delay\_2} \text{With IoT-SPO} = T_{\text{Wlan}} + T_{\text{AP\_to\_Server}} + (N-1) * T_{\text{AP\_to\_Server}} + T_{\text{IOT\_server}} + T_{\text{LUN\_write}} + N * T_{\text{Copy}} + T_{\text{Notification}} \)

![Scenario 2: 1 sender, 1 receiver, N frames (UDP)](image)

**Figure 18: Scenario 2 Testing Results**

Total Delay for Scenario 3 for the techniques:

- \( \text{Total\_Delay\_3} \text{Without IoT-SPO} = T_{\text{Wlan}} + T_{\text{AP\_to\_Server}} + (N-1) * T_{\text{AP\_to\_Server}} + N * T_{\text{Ack}} + T_{\text{IOT\_server}} + N * T_{\text{LUN\_write}} + N * T_{\text{AP\_to\_Server}} + N * T_{\text{Wlan}} \)

- \( \text{Total\_Delay\_3} \text{With IoT-SPO} = T_{\text{Wlan}} + T_{\text{AP\_to\_Server}} + (N-1) * T_{\text{AP\_to\_Server}} + N * T_{\text{Ack}} + T_{\text{IOT\_server}} + N * T_{\text{LUN\_write}} + N * T_{\text{Copy}} + T_{\text{Notification}} \)
Total Delay for Scenario 4 for the techniques:

- **Total_Delay_4 Without IoT-SPO =**
  
  \[ T_{\text{Wlan}} + T_{\text{AP_to_Server}} + (N-1)T_{\text{AP_to_Server}} + T_{\text{IOT_server}} + N*T_{\text{LUN.Write}} + N*T_{\text{AP_to_Server}} + N*T_{\text{Wlan}} \]

- **Total_Delay_4 with IoT-SPO =**
  
  \[ T_{\text{Wlan}} + T_{\text{AP_to_Server}} + (N-1)T_{\text{AP_to_Server}} + T_{\text{IOT_server}} + N*T_{\text{LUN.write}} + N*T_{\text{Copy}} + T_{\text{Notification}} \]
Use Cases

For growing crops and controlling pests with IoT, Monsanto (Predictive Sensor Machine) uses IoT technology to analyze soil, climate, and weather data and then make predictions on that information for specific yield estimates and planting plans. Monsanto will benefit from this approach by getting faster response and lower power consumption for the IoT devices. The approach will integrate with their program, Field Script, to analyze each farmer's unique field characteristics and then provide a specific prescription planting plan. Farmers download the plan to an iPad app called Field View to see real-time maps of their planting.
Conclusion

IoT is a game changing opportunity for all technology players. Unlocking insights and data on the many scenarios to which IoT can contribute will help customers driver operational efficiency, improve innovation, and enable creation of new business models. Working together will transform the business by starting from the customer’s existing assets and create new insights with analytics. The potential is as limitless as your imagination and as unique as each customer’s business.

This is the first approach made by our team in our roadmap regarding the contribution of the IoT industry. It was about optimizing the traffic throughput and latency on the uplink specifically and downlink as well. In essence, the network is a crucial IoT ecosystem component and has to be intelligent; not just a transport pipe.
Glossary

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<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>SAN</td>
<td>Storage Area Network</td>
</tr>
<tr>
<td>SPO</td>
<td>Storage Path Optimization</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
</tr>
</tbody>
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