Internet of Hybrid Opportunistic Things: A Novel Framework for Interconnecting IoTs and DTNs

Yiming Xu, V. Mahendran, and Sridhar Radhakrishnan
School of Computer Science
University of Oklahoma, Norman, Oklahoma 73019
Email: {yiming.xu, mahendran.veeramani, sridhar}@ou.edu

***Abstract*—Towards realizing the goal of connecting everything in every possible way to the Internet, researchers recently are focusing on connecting Internet of Things (IoTs) in challenged environments that suffer from disrupted connectivity. To this end, Delay-Tolerant Network (DTN) is considered as a potential enabler for providing communication in such environments.**

We argue that the existing approaches that integrate DTN as a mere communication substrate embedded in IoT devices, can only enable them to survive from disrupted environments. However, with such integration, the typical publish/subscribe semantics of IoT communications may not be utilized effectively. To the best of our knowledge, a unified hybrid framework that benefits from the semantics of both DTN and IoT communications is not yet proposed and implemented. In this work, we propose a novel and practical architectural framework for communications between IoTs and DTNs, and develop a working prototype on the off-the-shelf devices.

I. Introduction

In the current mobile Internet era, almost every practical thing around us is getting connected to the Internet. From household things such as refrigerators, shoes, and wristbands to industrial things such as smart-grid meters in smart-grid communication systems, every thing is being connected to the Internet. To extend connectivity over disrupted environments, the latest research [1], [2], [3] on Internet of Things (IoTs) is focused on enabling IoTs to be connected to Internet with the help networks such as Delay-Tolerant Networks (DTNs). For instance, to enable a delay tolerant IoT, the authors in [1] propose and implement DTN Bundle Protocol (BP) binding for IoT's Constrained Application Protocol (CoAP). This implementation [1] embeds DTN stack into the device, and the IoT application interacts with the integrated-DTN through a custom developed API, thereby creating a paradigm of IoT-over-DTN architecture. The authors in [2] consider a light-weight DTN BP protocol custom tailored for hardware-constrained IoT devices. The authors in [4] extend AllJoyn, a D2D-based communications framework with custom opportunistic communications.

The works such as [1], [2] that rely on Delay-Tolerant transport model as communications substrate would not benefit from IoT communications' typical semantics such as publish-subscribe model of forwarding. As a consequence, delivery performance of the IoT messages depend on the factors related

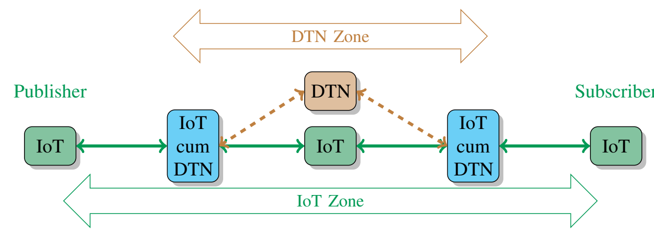

Fig. 1. Proposed IoT-cum-DTN framework

to the DTN transport such as routing, and other (non-IoT) DTN bundles[1] carried by the regular DTN nodes.

As an example application, we consider a practical urban mobile environment encompassing static IoT sensor nodes (publishers) deployed geographically over a region. A crowd-sourced DTN mule provides opportunistic connectivity to the deployed IoT publishers by carrying IoT messages in the form of bundles, and delivers to a set of remote IoT receiving devices (subscribers) that are connected to the Internet. The DTN mule is crowd-sourced to carry any DTN traffic in the region of interest (including non-IoT traffic). In such scenario, an end-to-end DTN transport approach such as [1] can suffer from reduced delivery throughput of IoT messages, as the deliverer (*i.e.*, DTN mule) is agnostic to the IoT messages encapsulated in the DTN bundle as a payload.

A. Contribution

To preserve the semantics of IoT, and also seamlessly utilize the DTN-based communications an 'IoT-cum-DTN' based framework is essential. To the best of our knowledge, such a framework of 'IoT-cum-DTN' is not proposed and implemented. To this end, we propose a novel Internet of Hybrid Opportunistic Things framework based on the aforementioned 'IoT-cum-DTN' paradigm. The proposed 'IoT-cum-DTN' architectural framework is shown in Fig. 1.

To realize an architecture of the IoT-cum-DTN node proposed in the framework as shown in Fig. 1; the following design principles are necessary:

- **Transparent DTN connectivity:** The IoT-cum-DTN node should communicate as a peer DTN node with *regular-DTN* nodes.

[1] A bundle is a basic unit of transmission in DTN.

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- **Transparent IoT P2P connectivity:** The IoT-cum-DTN node should enable P2P communication with the respective IoT publisher and IoT subscriber nodes.
- **DTN IoT Interoperability:** To fully utilize DTN's persistent storage and robustness from node failures, the IoT-cum-DTN node needs to seamlessly encapsulate IoT messages as DTN bundles. Subsequently, the IoT messages have to be retrieved (from bundles) upon meeting a regular IoT node.

To realize an architecture with the aforementioned design-principles, a vertical-plane integration of IoT and DTN stacks is necessary. To this end, we propose IoT as a convergence layer transport to the existing DTN stack, and empower convergence-layer adapter with bundle construction, and storage access. For our implementation, we have used a standard DTN2 reference implementation for embedded devices, namely IBR-DTN [5]. The IoT protocol considered is MQTT-SN [6], a client-server based publish/subscribe messaging transport protocols for wireless nodes such as Sensor Networks. The native MQTT-SN is based on client-server model, different neighbor discovery beacons are used by the respective server and clients for identifying their peer nodes. We therefore, modified MQTT-SN towards using a custom beacon protocol to enable simple P2P neighbor discovery. As the payload-contents of custom neighbor discovery beacon are not used by MQTT-clients, we used the beacons' payload to contain information necessary for the regular DTN nodes to recognize them.

The architecture of the IoT-cum-DTN node based MQTT-SN and IBR-DTN is shown in Fig. 2. In addition to the regular UDP, and TCP convergence layer, we have implemented MQTT components as a new convergence layer. The MQTT Convergence Layer Adapter (CLA) binds the MQTT components, namely broker, publisher, subscriber to the IBR-DTN's Bundle daemon. Furthermore, we extended MQTT CLA with a cross-layer design, to have direct access to the IBR-DTN's persistent storage. This cross-layer design, enables the MQTT-CLA and underlying MQTT stack to act as a independent IoT process, that enacts the transparent IoT P2P connectivity. The MQTT-CLA also has the feature of DTN-bundle construction from the received MQTT message from an IoT publisher, and de-encapsulate bundle to retrieve actual MQTT message for the IoT subscriber reception. The demo snapshot of the working prototype of IoT-cum-DTN node with MQTT convergence layer is shown in Fig. 3. The current DTN node takes the role of MQTT-subscriber to receive the message, and the peer DTN node functions as MQTT-publisher that sends the message as publisher.

II. Conclusion

We have proposed a novel IoT-cum-DTN architecture framework, and implemented the node from the existing standards of DTN and IoT. A working prototype of seamless hybrid IoT with communication to DTN and IoT has been developed.

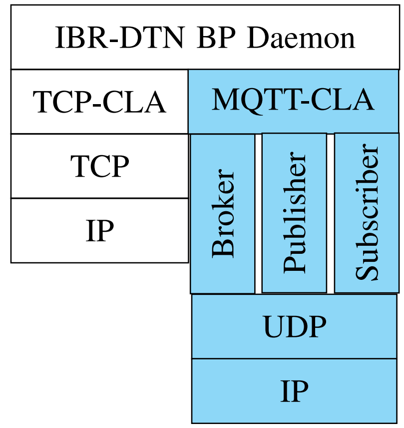

Fig. 2. Proposed IoT-cum-DTN Gateway Node Architecture. The extended modules are shown in *blue shaded boxes*.

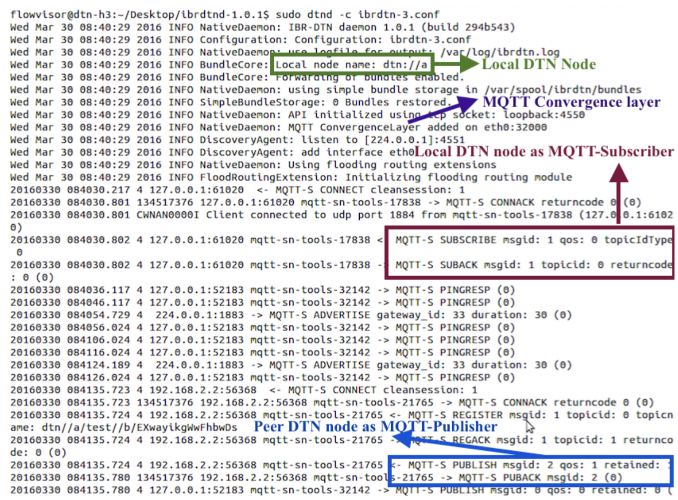

Fig. 3. Snapshot of DTN-cum-IoT bundle daemon running MQTT-convergence layer. The node behaves as MQTT-Subscriber, and receives a message from the peer DTN node behaving as MQTT-publisher.

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