Releasing the Potential of Information-centric IoT Networks

Cenk Gündoğan, advised by Thomas C. Schmidt
HAW Hamburg
{cenk.guendogan, t.schmidt}@haw-hamburg.de

***Abstract*—Current research considers Information-centric Networking (ICN) as a promising communication paradigm for the constrained IoT. Challenged environments face intermittent connectivity, mobility, and bandwidth limitations, which are addressed with tremendous effort on varying layers of the IPv6 network stack. ICN removes the Internet's end-to-end principle by decoupling data from locations, providing in-networking caching, and enabling multicast as a protocol primitive. These characteristics allow for lightweight IoT deployments that intrinsically support consumer mobility and multi access to content.**

In my thesis, I focus on the Named-Data Networking (NDN) ICN flavor and pursue a seamless integration of NDN into wireless low-power and lossy networks (LLNs). My current investigation and contribution includes (i) a convergence layer for low-power link layer technologies that supports packet header compression as well as link fragmentation, and (ii) a publish–subscribe option for NDN that maintains a routing system with minimal forwarding state requirements to reliably disseminate content in large-scale LLNs. My upcoming research focuses on Quality of Service mechanisms to enable resource allocation decisions on the network and link layer as well as to improve NDN caching strategies for high prioritized traffic flows.

***Index Terms*—Internet of things, Information-centric networking**

I. Introduction

The Internet of Things (IoT) connects numerous heterogeneous devices to the Internet. Many scenarios require appliances that use battery-operated microcontrollers with limited processing and memory resources to deliver sensory data. Especially industrial settings in hazardous environments have to meet safety-critical requirements and ensure regulatory compliance by providing reliable streams of telemetry. Deployments in such environments typically utilize stationary devices as an uplink and portable handhelds on field workers to transmit collected sensor readings to remote cloud services. These portables connect wirelessly via low-power and lossy networks (LLNs) to form stub networks and are exposed to mobility, intermittent connectivity, and network disruptions.

The IETF designed and extends an IPv6 based protocol suite that meets the demanding requirements of a constrained IoT. In contrast to this host-centric approach, research indicates that pluralistic networking paradigms, like Information-centric Networking (ICN), may be rewarding for networked devices that operate in LLNs without perpetual connectivity. Particularly the Named Data Networking (NDN) [1] approach positively affects challenged IoT deployments [2] due to its name-based routing, stateful forwarding, and in-network caching. These benefits include a reduced network stack complexity, less traffic overhead due to hop-wise retransmissions, and an increased robustness in multi-hop scenarios.

II. Research Challenges & Contributions

In my thesis, I work on a seamless integration of NDN into wireless and multi-hop LLNs to unfold the potentials of ICN for challenged IoT networks. My current contribution is twofold. It includes (i) an ICN convergence layer for low-power link layers, and (ii) a disruption-tolerant publish–subscribe option to reliably disseminate sensor readings.

A. Link Layer Convergence

Typical low-power link layer technologies have restrictions and lack basic protocol features. The IEEE 802.15.4 technology, e.g., has a limited maximum physical packet size of 127 bytes and does not support frame encapsulation formats (cf. EtherTypes in Ethernet) to identify the upper layer protocol. A convergence layer is thus necessary to operate NDN directly on top of low-power link layers.

My contributions in this area include the ICNLoWPAN [3] convergence layer that is motivated by and inherits features from the 6LoWPAN [4] counterpart. ICNLoWPAN and 6LoWPAN are situated between the link layer and the actual network layer, such that messages are translated appropriately on each hop for sending and receiving. This allows for a transparent adaptation of network layers, without requiring modifications.

ICNLoWPAN features stateless and stateful compression mechanisms to reduce packet header overhead. It further inherits the 6LoWPAN dispatching framework and reuses its link fragmentation scheme to allow for messages larger than MTU limitations. Reutilizing 6LoWPAN components also enables a parallel operation of NDN and IPv6 over the same links and reduces overall memory consumption.

I implemented ICNLoWPAN on RIOT OS [5] and CCN-lite [6] to experiment with real IoT hardware using the IEEE 802.15.4 radio technology as a first step, and Bluetooth Low Energy (BLE) thereafter. Since long-range and cellular radios gain more and more momentum, my investigations will further focus on adaptations for LoRa and NB-IoT.

B. Routing

NDN uses name-based routing to forward requests towards named data objects (NDOs). In contrast to fixed-length IP addresses, NDN names are of arbitrary length and consist of an indefinite number of components, so NDN uses a potentially much larger address space than typical IP deployments. Furthermore, common IoT networks generate exceedingly more data objects than the number of prevalent hosts. The regular NDN forwarder thus consumes much more memory to store forwarding state compared to an IP forwarder.

My contributions in this subject include HoP-and-Pull (HoPP) [7], which is a disruption-tolerant Publish–Subscribe scheme for lightweight IoT deployments with hard memory limitations. In HoPP, constrained IoT nodes form a multi-hop stub network and are connected to gateways with up-stream connectivity. While IoT nodes are battery-operated and resource-constrained, gateways typically are more stable and powerful. One or several gateways are selected to act as Content Proxies (CPs) and take the role of data caches and persistent access points. A CP distributes sub-network prefixes on the IoT deployment side, so that IoT nodes only install prefix-specific default routes into the forwarding table to minimize memory consumption.

I implemented HoPP on RIOT OS and CCN-lite to evaluate the benefits in an IoT testbed with hundreds of IoT nodes. Our experimental evaluations [2], [7] show that HoPP reliably operates in large-scale deployments with frequent data transmissions. Due to its hop-wise data propagation and its corrective actions in case of failed publishes, HoPP is able to republish on alternative paths, reactively rebalance the routing system, and delay publishes until a disrupted network reconnects. My further investigation will include the integration of a group communication feature to improve on the reliability in disrupted networks, such that content is published to several backup CPs.

III. Research Outlook

Typical IoT deployments face resource constraints on many levels. Nodes have processing and memory limitations, the underlying link layer technology has bandwidth and latency restrictions. Particularly in multi-hop networks, such constraints affect the overall performance and create bottlenecks that lead to packet loss and energy depletion. Quality of Service (QoS) is usually achieved with techniques of managed unfairness—whenever one traffic flow is given a higher priority, another is essentially deprived of its resources.

While my effort to refine ICNLoWPAN and HoPP is continuing, my immediate research will further concentrate on QoS in named-data IoT networks. For this, I will investigate two sub-categories separately: (i) traffic flow classification, and (ii) resource control allocation.

A. Traffic Flow Classification

In IP-based networks, traffic flows are typically identified using the 5-tuple $(ip_{src};\ port_{src};\ ip_{dst};\ port_{dst};\ protocol)$ and thus exist between pairs of endpoints. NDN-based networks cannot reuse this strategy, because of two major differences. First, messages are forwarded using content names instead of host addresses and thus cannot be identified using host addresses. Second, a flow potentially consists of several sub-flows with an indefinite number of participating endpoints due to the inherent multicast support and transparent content stores along paths. A first step to flow classification techniques for ICN is given in [8]. However, the suitability for IoT networks still requires an exhaustive evaluation.

B. Resource Allocation Control

Initially, my research focuses on three different resources relevant to the IoT. (i) Available link bandwidth at a forwarder, (ii) *Pending Interest Table (PIT)* space, i.e., the amount of open requests on each forwarder, and (iii) content store space at a forwarder for caching NDOs. It is noteworthy that consumers affect the PIT space of all forwarders during requests and caching strategies govern content store space of the same forwarders during incoming responses from producers.

The mapping of traffic flows to priorities as much as the distribution and maintenance of priority levels in a named-data IoT network remain open issues that I plan to address in my research. HoPP may be one viable option to propagate resource reservation configurations.

C. Next Steps

My first step is to augment RIOT OS and CCN-lite with a module that measures and reports resource usages for all resources defined in section III-B. I will then follow with an implementation of a traffic flow classification mechanism that is appropriate for the IoT and will evaluate the resource reservations for high and low prioritized traffic flows in a large-scale IoT testbed. Since HoPP may serve as a viable carrier for resource reservation configurations, I will extent it to propagate traffic class priorities and resource allocation strategies.

References

[1] V. Jacobson, D. K. Smetters, J. D. Thornton, and M. F. Plass, "Networking Named Content," in *5th Int. Conf. on emerging Networking Experiments and Technologies (ACM CoNEXT'09)*. New York, NY, USA: ACM, Dec. 2009, pp. 1–12.

[2] C. Gündogan, P. Kietzmann, M. Lenders, H. Petersen, T. C. Schmidt, and M. Wählisch, "NDN, CoAP, and MQTT: A Comparative Measurement Study in the IoT," in *Proc. of 5th ACM Conference on Information-Centric Networking (ICN)*. New York, NY, USA: ACM, September 2018.

[3] C. Gündogan, T. C. Schmidt, M. Wählisch, C. Scherb, C. Marxer, and C. Tschudin, "ICN Adaptation to LowPAN Networks (ICN LoWPAN)," IRTF, IRTF Internet Draft – work in progress 01, November 2018. [Online]. Available: https://tools.ietf.org/html/draft-irtf-icnrg-icnlowpan

[4] G. Montenegro, N. Kushalnagar, J. Hui, and D. Culler, "Transmission of IPv6 Packets over IEEE 802.15.4 Networks," IETF, RFC 4944, 2007.

[5] E. Baccelli, et. al., "RIOT: an Open Source Operating System for Low-end Embedded Devices in the IoT," *The IEEE Internet of Things Journal*, 2018.

[6] C. Tschudin, C. Scherb *et al.*, "CCN Lite: Lightweight implementation of the Content Centric Networking protocol," 2018. [Online]. Available: http://ccn-lite.net

[7] C. Gündogan, P. Kietzmann, T. C. Schmidt, and M. Wählisch, "HoPP: Robust and Resilient Publish-Subscribe for an Information-Centric Internet of Things," in *Proc. of the 43rd IEEE Conference on Local Computer Networks (LCN)*. Piscataway, NJ, USA: IEEE Press, Oct. 2018.

[8] I. Moiseenko and D. Oran, "Flow Classification in Information Centric Networking," IETF, Internet-Draft – work in progress 02, July 2018.