Defragmenting the Internet of Things: Towards Integration of Bluetooth Low Energy

Hauke Petersen
Advisor: Prof. Matthias Wählisch
Institute of Computer Science
Freie Universität Berlin
Berlin, Germany
hauke.petersen@fu-berlin.de

***Abstract*—Integrating Bluetooth Low Energy (BLE) more tightly into the Internet of Things (IoT) by establishing it as one of the goto transports for IP- and ICN-based networks has a high potential in the process of defragmenting the IoT. To achieve this goal, a deeper understanding, not only on network aspects, but also on system aspects is needed. This research proposal sketches a path toward this goal.**

***Index Terms*—Bluetooth Low Energy, Internet of Things, Information Centric Networking, RIOT**

I. Introduction

The Internet of Things (IoT) is highly fragmented. Based on the experiences of the current Internet, we need to overcome this fragmentation by converging towards a set of common protocols to achieve interoperability, but without loosing innovation.

One major example for defragmentation on the network level is the standardization effort by the IETF, most prominently *6LoWPAN*. Although initially only defined for IEEE802.15.4-based networks, a number of follow up standards have been developed, applying the same principles to run IPv6 over many different transports, Bluetooth Low Energy (BLE) being one of them.

Comparing BLE with IEEE802.15.4 in this context, BLE offers some appealing properties: its link layer provides time sliced channel hopping as well as different data rate options (since Blutetooth 5.0). Additionally, BLE is already one of the most deployed low-power network technologies, due to its support on mobile platforms. Utilizing these as IP border routers for BLE-based constrained node networks offers great potential, as the lack of deployed border routers for IEEE802.15.4-based networks is a limiting factor for a wide spread adaption of the IoT.

As candidate towards defragmenting the IoT, recent research has shown that the use of ICN protocols for constrained node networks yields very promising results [2], [4]. In certain scenarios, the network performance has been superior to IP-based setups [5]. So far, IEEE802.15.4 has been the most prominently used link layer technology also in this field. BLE promises to be a suitable alternative here as well, but further exploration of this topic this is needed.

Another example for defragmentation in the IoT on the system level is the rise of open-source operating systems (OS) such as RIOT [1], which particularly target Internet-connected, resource constrained, embedded platforms. Such OSes introduce clearly defined abstraction layers on a software and system level that allow for hardware independent software development and a high degree of portability.

Due to the standardization background of Bluetooth, there is a lack of vendor independent, open-source, and portable BLE stack implementations, allowing to integrate BLE with existing IP stacks running on the aforementioned software platforms. Furthermore, most implementations are geared towards full-featured BLE implementation, rather than being optimized for IP-over-BLE scenarios. Focusing on the latter would allow for saving significant resources in terms of memory and computational overhead, and thus decrease power consumption.

II. State of the Art

There exists extensive research on the link layer properties of BLE, covering e.g. energy consumption, connection parameter optimization, and comparison to other link layer technologies. Also the topic of multihop topologies and routing in these setups has been extensively discussed in the scientific community. However, only limited work on the implications of IP-based traffic on these setups is available (e.g. [7]). There is no work analyzing the overall network performance when running high-level application layer protocols such as *CoAP* or *MQTT-SN*.

Running ICN protocols over BLE-based networks is, as of today, a largely unexplored topic.

III. Research Question

The central driver of my research it to help **decrease the fragmentation of the IoT** on the network and system levels by pushing the adaption and integration of open standards and platforms.

Bluetooth Low Energy presents itself as a very competitive technology for connecting low-power, constrained devices. Today, it is largely used outside of the context of IP-based networks, hence adding to the fragmentation of the IoT space. Using BLE to run IP-based networking would mitigate this issue, and the needed protocol mapping is standardized for some time now.

My goal is to answer the subsequent question: **why is BLE not a goto solution for connecting constrained node networks with the Internet today?** While the contained political and market related aspects are not in the scope of this proposal, there are a number of open issues and uncertainties on the network and system levels to be exploited:

- Connection handling: the IP-over-BLE standard expects BLE nodes to open connections, but the corresponding standards do not specify when and by whom these connections are established. This is especially of interest, as memory constraints severely limit the maximum number of connections per device.
- Multicast traffic: IP-based BLE networks are based on point-to-point connections, with no notion of multicast and broadcast communication. Although BLE provides broadcast capabilities through its advertisement data channels, new concepts are needed for closely interfacing these from IP stack protocols.
- Routing: the absence of broadcast and multicast messaging per default is a particular challenge for routing protocols.
- System-level interoperability: BLE is massively deployed on mobile devices, but platforms such as Android or iOS do not offer APIs for programming against BLE's L2CAP layer, thus preventing implementation of the IP adaption code without hacking the OSes kernels.
- Missing experimentation platforms: as most BLE platforms are closed source and provided by vendors with no particular interest in using IP-over-BLE, there is a lack and open and accessible platforms on constrained devices to be used for experiments. The same is true for public available testbeds.
- Standardization: BLE is capable of building multi-hop networks since 2013 (Bluetooth 4.1), but the adaption of RFC7668 to allow for more than star topologies has just recently been picked up.

Addressing those items for IP-based networks, my second question is raised: **can we transfer this knowledge to efficiently run ICN-based networks over BLE?** Transferring ICN packets over connection based L2CAP channels has not been researched so far, so applying the approaches standardized in RFC7668 seems like a natural starting point in investigating the integration of ICN and BLE. The key issues to be addressed are very similar to the open issues for IP over BLE, but the following items are of my particular interest:

- Caching and BLE characteristics: if nodes lose connectivity to a network, it can take some time until they reconnect, in particular when using long advertisement intervals. The in-network caching capabilities of ICN could potentially help mitigating these effects, decreasing retransmissions and improving packet delivery rates.
- Efficient implementation: the point-to-point based nature of BLE networks allows a straight forward mapping onto ICN faces. Utilizing this on an implementation level does potentially allow for streamlining implementations.

IV. Contributions and Next Steps

Towards defragmenting the IoT, the aim of my research is to help answer the above questions by advancing the knowledge about network level behavior for BLE based, multihop IP and ICN networks, while in parallel pushing for open and portable software platforms.

The general approach for this is based on running code and (large scale) testbed experiments. The aim is to establish a set of fully automated testbed experiments that are to be extended and re-used in the course of my work. RIOT [1] as a software platform and the FIT IOT-LAB as testbed [3] are selected as the cornerstones.

In particular, adding to the knowledge about the behavior of high-level application protocols, such as CoAP and MQTT-SN, in BLE-based networks is a key point. This work will hopefully also prove useful for the IETF's current standardization process on multihop IPv6 over BLE.

A second contribution will be initial implementations and large-scale measurements of BLE-based multihop networks running ICN flavors. Specifically, applying the concepts for integrating RPL with BLE presented by Lee et al. [8] to the NDN-based publish-subscribe pattern presented by Gündoğan et. al. [6] promises to yield interesting results.

Third, all tools and implementations will be based on open platforms, and be released under open source licenses. This, in conjunction with the use of openly accessible testbeds, allows for reproducibility of results, often a problem for large scale network experiments. Furthermore it provides others with a transparent and reusable base for any future research.

The next concrete step will be to extend our comparative study of IoT application layer protocols [5] by re-running the experiments on a BLE-based network. This includes novel work on running NDN over BLE, for which I already implemented a first prototype.

References

[1] E. Baccelli, C. Gündoğan, O. Hahm, P. Kietzmann, M. S. Lenders, H. Petersen, K. Schleiser, T. C. Schmidt, and M. Wählisch. Riot: an open source operating system for low-end embedded devices in the iot. *IEEE Internet of Things Journal*, 2018.

[2] E. Baccelli, C. Mehlis, O. Hahm, T. Schmidt, and M. Wählisch. Information Centric Networking in the IoT: Experiments with NDN in the Wild. In *Proc. of ACM ICN*. ACM, 2014.

[3] C. Adjih et. al. Fit iot-lab: A large scale open experimental iot testbed. In *Internet of Things (WF-IoT), 2015 IEEE 2nd World Forum on*, pages 459–464. IEEE, 2015.

[4] C. Gündogan et. al. Information-centric networking for the industrial iot. In *Proceedings of the 4th ACM Conference on Information-Centric Networking*, ICN '17, pages 214–215, New York, NY, USA, 2017. ACM.

[5] C. Gündoğan, P. Kietzmann, T. C. Schmidt, M. Lenders, H. Petersen, and M. Wählisch. NDN, CoAP, and MQTT: A Comparative Measurement Study in the IoT. In *Proceedings of the 5th ACM Conference on Information-Centric Networking*. ACM, 2018.

[6] 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, Oct. 2018. IEEE Press.

[7] M. Spörk, et. al. Bleach: Exploiting the full potential of ipv6 over ble in constrained embedded iot devices. In *Proceedings of the 15th ACM Conference on Embedded Network Sensor Systems*, page 2. ACM, 2017.

[8] T. Lee et. al. A synergistic architecture for rpl over ble. In *Sensing, Communication, and Networking (SECON), 2016 13th Annual IEEE International Conference on*, pages 1–9. IEEE, 2016.