Experimenting with an SDN-Based NDN Deployment over Wireless Mesh Networks

Sarantis Kalafatidis*‡, Vassilis Demiroglou*†, Lefteris Mamatas*‡, Vassilis Tsaoussidis*†
* *Athena Research and Innovation Center, Greece*
† *Department of Electrical and Computer Engineering, Democritus University of Thrace, Greece*
{vdemirog, vtsaousi}(at)ee.duth.gr
‡ *Department of Applied Informatics, University of Macedonia, Greece*
{kalafatidis, emamatas}(at)uom.edu.gr

***Abstract*—Internet of Things (IoT) evolution calls for stringent communication demands, including low delay and reliability. At the same time, wireless mesh technology is used to extend the communication range of IoT deployments, in a multi-hop manner. However, Wireless Mesh Networks (WMNs) are facing link failures due to unstable topologies, resulting in unsatisfied IoT requirements. Named-Data Networking (NDN) can enhance WMNs to meet such IoT requirements, thanks to the content naming scheme and in-network caching, but necessitates adaptability to the challenging conditions of WMNs.**

In this work, we argue that Software-Defined Networking (SDN) is an ideal solution to fill this gap and introduce an integrated SDN-NDN deployment over WMNs involving: (i) global view of the network in real-time; (ii) centralized decision making; and (iii) dynamic NDN adaptation to network changes. The proposed system is deployed and evaluated over the w-iLab.1 Fed4FIRE+ test-bed. The proof-of-concept results validate that the centralized control of SDN effectively supports the NDN operation in unstable topologies with frequent dynamic changes, such as the WMNs.

***Index Terms*—Software-Defined Networks, Information-Centric Networking, Named Data Networking, Wireless Mesh Networks, Internet of Things**

I. Introduction

The emerging and ubiquitous Internet of Things (IoT) technology brings a profound quality impact to our every-day life with its diverse applications, including e-health monitoring, environmental quality notification and Smart-City applications [1]. Such IoT applications are typically associated with critical performance requirements, such as low-delay, reduced communication overhead and high resilience. Thus, the efficient functionality of these applications is inherently associated with the IoT network performance.

Several IoT networks are encompassing wireless mesh technology, in order to increase their communication range in a multi-hop manner. Indeed, Wireless Mesh Networks (WMNs) fulfill the multi-hop communication needs of distant or infrastructure-free IoT deployments (e.g., Smart-City, Environmental Monitoring), however are facing unstable topologies, connection failures and low-quality communication (e.g., due to signal interference, mobility). These arising issues are impacting the performance of IoT applications, as they can not meet the aforementioned requirements.

In this context, Named-Data Networking (NDN) [2], an Information-Centric Networking (ICN) [3] architecture, has been proposed as a promising approach to match the IoT application requirements [4]. In particular, NDN architecture: (i) facilitates content retrieval from the network, as NDN packets contain data names instead of IP addresses; and (ii) contributes to reduced communication overhead thanks to the in-network caching [5]. However, deploying NDN in such dense wireless mesh networks requires to employ additional mechanisms that rapidly detect network changes and appropriately adjust the NDN nodes.

Software-Defined Networking (SDN) is ideal to provide the missing features of intelligent centralized control and programmability of the NDN networks. In summary, we consider the following features offered by the integration of SDN with NDN over WMNs: (i) adaptation to dynamic changes (e.g., when a new NDN node participates in the network); (ii) flexibility in the network (e.g., using alternative paths depending on the network state); (iii) reliability/fault tolerance by the rapid detection of network failures; and (iv) content-aware decision making based on caching information.

In this work, we present our SDN-based solution to facilitate NDN adaptability in unstable wireless mesh networking conditions. In particular, our approach exploits the advantages of SDN-NDN integration enabling efficient NDN Interest-Data exchange (in terms of network delay). Our solution encompasses: (i) a global view of network topology in real-time; (ii) centralized decision making (including content-based decision making and best-path selection) and (iii) dynamic NDN adaptation to network changes.

Our proof-of-concept evaluation involves experimentation over a real WMN, investigating both the control overhead and the data messages exchange performance (e.g., NDN packets). The evaluation results affirm the deployability of the proposed system, illustrate our system's delay performance and validate the experimental methodology. Our contributions include:

- a novel SDN-NDN integration system over mesh networks.

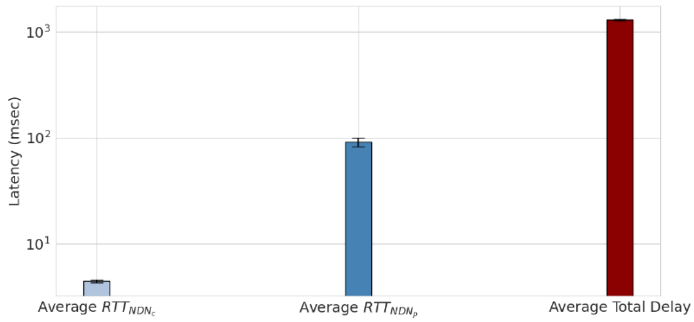

Fig. 4. Average RTT_{NDN_c}, RTT_{NDN_p} and *Total Delay*.

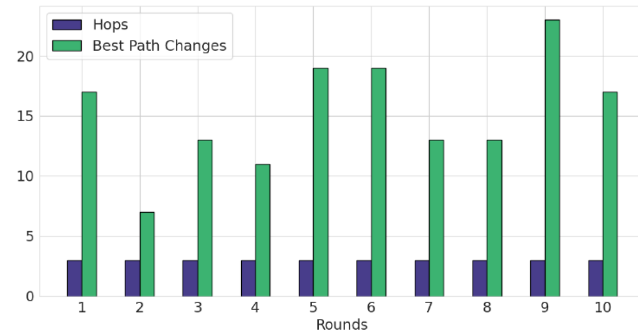

Fig. 5. Number of Hops and *Best Path Changes (BPC)* pers round.

NDN operation in unstable topologies with frequent dynamic changes, such as the WMNs.

We plan to carry out further investigations and extend the capabilities of our approach. These include:

- Extensive experimentation analysis and performance evaluation of our approach in more complex experimental scenarios (e.g., large-scale wireless mesh deployments, multiple Consumers and Producers).
- Extension of the Controller capabilities improving its decision making, taking into account additional NDN-related information (e.g., caching information of the intermediate network nodes, communication with the Producer).
- Evaluation of our approach over challenging network environments (e.g., signal interference of crowded areas, outdoor wireless conditions, long-distance), such as Smart-City networks. We plan to conduct experiments in the City-Lab test-bed [11] which provides real Smart-City conditions.
- Adopting a multi-protocol solution, i.e., also supporting on-demand Delay/Disruption Tolerant Networking (DTN), in order to provide further reliability support in highly-disruptive networking conditions (e.g., mobility, prolonged delays, frequent disruptions, link failures). In this context, we can also enable the seamless NDN operation in such challenging networking conditions with the NDN-over-DTN stack [19].

ACKNOWLEDGMENT

This work has received funding from the EU's Horizon 2020 research and innovation programme through the 9th open call scheme of the Fed4FIRE+ project (grant agr.num. 732638).

REFERENCES

[1] J. A. Stankovic, "Research directions for the internet of things," *IEEE Internet of Things Journal*, vol. 1, no. 1, pp. 3–9, 2014.

[2] L. Zhang, A. Afanasyev, J. Burke, V. Jacobson, K. Claffy, P. Crowley, C. Papadopoulos, L. Wang, and B. Zhang, "Named data networking," *ACM SIGCOMM Computer Communication Review*, vol. 44, no. 3, pp. 66–73, 2014.

[3] G. Xylomenos, C. N. Ververidis, V. A. Siris, N. Fotiou, C. Tsilopoulos, X. Vasilakos, K. V. Katsaros, and G. C. Polyzos, "A survey of information-centric networking research," *IEEE Communications Surveys Tutorials*, vol. 16, no. 2, pp. 1024–1049, 2014.

[4] A. Aboodi, T.-C. Wan, and G.-C. Sodhy, "Survey on the incorporation of ndn/ccn in iot," *IEEE Access*, vol. 7, pp. 71827–71858, 2019.

[5] C. Yi, A. Afanasyev, I. Moiseenko, L. Wang, B. Zhang, and L. Zhang, "A case for stateful forwarding plane," *Computer Communications*, vol. 36, no. 7, pp. 779–791, 2013.

[6] M. Selimi, L. Navarro, B. Braem, F. Freitag, and A. Lertsinsrubtavee, "Towards information-centric edge platform for mesh networks: The case of citylab testbed," in *2020 IEEE International Conference on Fog Computing (ICFC)*, pp. 50–55, 2020.

[7] E. Aubry, T. Silverston, and I. Chrismen, "Implementation and evaluation of a controller-based forwarding scheme for ndn," in *2017 IEEE 31st International Conference on Advanced Information Networking and Applications (AINA)*, pp. 144–151, 2017.

[8] M. Alhowaidi, D. Nadig, B. Ramamurthy, B. Bockelman, and D. Swanson, "Multipath forwarding strategies and sdn control for named data networking," in *2018 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, pp. 1–6, 2018.

[9] M. Amadeo, C. Campolo, G. Ruggeri, A. Molinaro, and A. Iera, "Understanding name-based forwarding rules in software-defined named data networking," in *ICC 2020 - 2020 IEEE International Conference on Communications (ICC)*, pp. 1–6, 2020.

[10] "Wireless Testlab and OfficeLab — imec iLab.t documentation." https://doc.ilabt.imec.be/ilabt/wilab/. Accessed: 2022-01-15.

[11] J. Struye, B. Braem, S. Latré, and J. Marquez-Barja, "The citylab testbed — large-scale multi-technology wireless experimentation in a city environment: Neural network-based interference prediction in a smart city," in *IEEE INFOCOM 2018 - IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)*, pp. 529–534, 2018.

[12] Q.-Y. Zhang, X.-W. Wang, M. Huang, K.-Q. Li, and S. K. Das, "Software defined networking meets information centric networking: A survey," *IEEE Access*, vol. 6, pp. 39547–39563, 2018.

[13] "BATMAN Concept - open-mesh - open mesh." https://www.open-mesh.org/projects/open-mesh/wiki/BATMANConcept. Accessed: 2022-01-15.

[14] "NFD Overview — Named Data Networking Forwarding Daemon (NFD) 0.7.1 documentation." https://named-data.net/doc/NFD/current/overview.html. Accessed: 2022-01-15.

[15] "Empowering App Development for Developers — Docker." https://www.docker.com/. Accessed: 2022-01-15.

[16] "Wiki - alfred - Open Mesh." https://www.open-mesh.org/projects/alfred/wiki. Accessed: 2022-01-15.

[17] "jFed." https://jfed.ilabt.imec.be/. Accessed: 2022-01-15.

[18] S. K. Fayazbakhsh, Y. Lin, A. Tootoonchian, A. Ghodsi, T. Koponen, B. Maggs, K. Ng, V. Sekar, and S. Shenker, "Less pain, most of the gain: Incrementally deployable icn," in *Proceedings of the ACM SIGCOMM 2013 Conference on SIGCOMM*, SIGCOMM '13, (New York, NY, USA), p. 147–158, Association for Computing Machinery, 2013.

[19] C. A. Sarros, V. Demiroglou, and V. Tsaoussidis, "Intermittently-connected iot devices: Experiments with an ndn-dtn architecture," in *2021 IEEE 18th Annual Consumer Communications Networking Conference (CCNC)*, pp. 1–9, 2021.