Using SmartMesh IP in Smart Agriculture and Smart Building Deployments: it Just Works

Keoma Brun-Laguna[a], Rémy Léone[a], Xavier Vilajosana[b], Thomas Watteyne[a]

[a] *Inria, EVA team, Paris, France*
[b] *Univ. Oberta de Catalunya, Barcelona, Catalonia, Spain*

Abstract

We deploy two low-power wireless networks, one in a Smart Agriculture setting (a peach orchard), one in a Smart Building. Both networks use out-of-the-box SmartMesh IP technology to gather sensor values, as well as extensive network statistics. This article presents an in-depth analysis of the performance of both networks, and compares them. Nodes in both exhibit end-to-end reliability of 100%, with an expected lifetime between 4 and 8 years.[Thomas] above? We show how – contrary to popular belief – wireless links are symmetric. Thanks to the use of Time Slotted Channel Hopping (TSCH), the network topology is very stable, with ≤15 link changes on average per day in the entire network. We conclude that SmartMesh IP technology is perfectly applicable for and Smart Building applications.

Keywords: Low-power wireless, SmartMesh IP, TSCH, 6TiSCH, Smart Agriculture, Smart Building.

1. Introduction

Peaches do not like frost. If during the blooming season (September in Argentina), temperature gets below -3 C for only a couple of hours, the flowers freeze, and no peaches are produced. In 2013, 85% of the peach production in the Mendoza region (Western Argentina) was lost because of frost events. Farmers can lose everything in only a couple of hours. Yet, if they are warned of a frost event a couple of hours ahead, they can install heaters throughout the orchards, and use big fans to move the hot air around. Fighting the frost events is not the issue, what is hard is predicting it.

The goal of the Smart Agriculture deployment (part of the PEACH project [7]) is to predict frost events in a peach orchard. We install sensors around the orchard that measure air temperature, air relative humidity, soil moisture and soil

Email addresses: `keoma.brun@inria.fr` (Keoma Brun-Laguna), `remy.leone@inria.fr` (Rémy Léone), `xvilajosana@uoc.edu` (Xavier Vilajosana), `thomas.watteyne@inria.fr` (Thomas Watteyne)

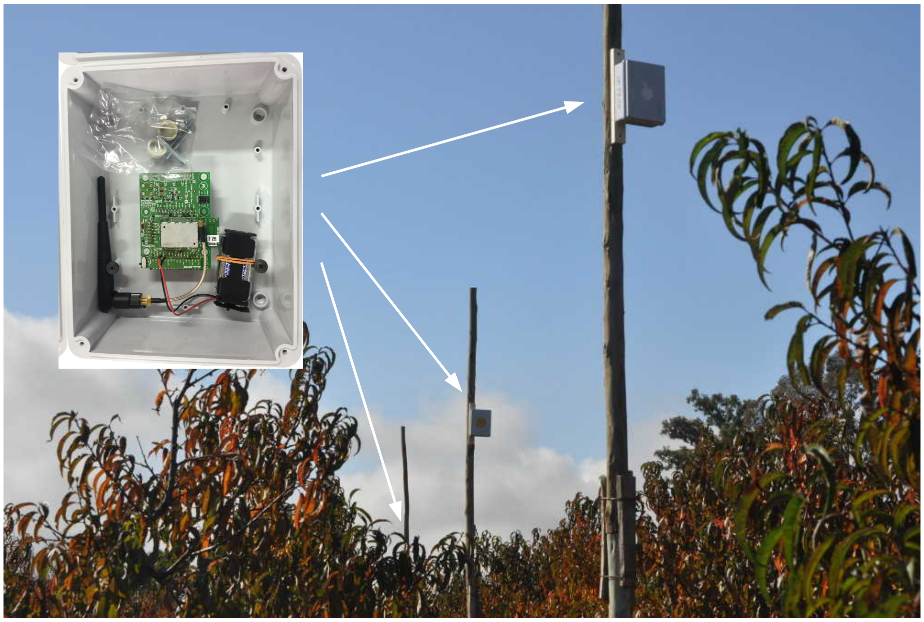

Figure 1: Areal view of the low-power wireless network deployed in a peach orchard near Mendoza, Argentina.

Figure 2: The wireless motes deployed in the Inria office building outdoor, France.

Figure 3: The wireless motes deployed in the Inria office building indoor, France.

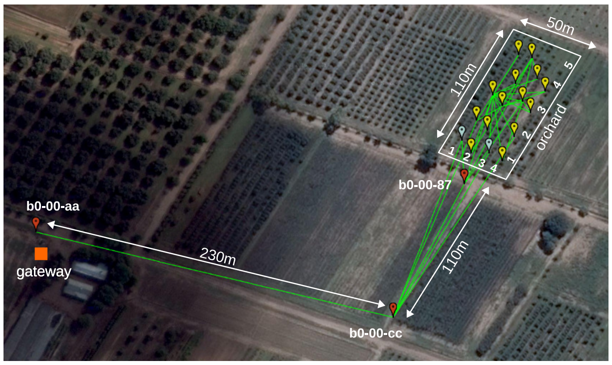

Figure 4: The wireless motes deployed in the peach orchard in Mendoza, Argentina.

Figure 5: The wireless motes deployed in the Inria office building, France.

temperature. We feed the collected data into a database, and by analyzing the data in real-time using machine learning, we can identify patterns in the data and predict frost events.

Because of the heavy machinery that moves inside the orchard, using cables to interconnect the sensors is not an option. The main challenge is to deploy a system that provides both high end-to-end reliability and long lifetime, without using cables. We use SmartMesh IP off-the-shelf, the low-power wireless mesh solution from Analog Devices. The sensor devices are battery-powered and equipped with a radio. They form a multi-hop topology, and collaborate to route the data generated by the devices (called "motes") to a gateway. This gateway is connected to the Internet, and forwards the gathered date to the servers in Paris, France. Data appears on the web interface of the servers seconds after it was gathered by the sensor network.

The Smart Agriculture network is deployed in a peach orchard of 204 trees, planted in a 50 m $\times$ 100 m area (shown in Fig. 4). The low-power wireless network is composed of 18 sensor motes uniformly distributed between the peach trees, and 3 relay motes to connect the orchard to the gateway some 300 m away. Each mote is placed in a water-tight box that is fixed on a 4 m high pole (see Fig. 1).

To complement and compare the network performance gathered from the Smart Agriculture deployment, we deploy a second Smart Building low-power wireless network in an office building in Paris. 14 motes are placed on the ceiling of one floor of the building, 3 additional motes are placed right outside the building, on lamp posts (Fig. 5). The 14 motes inside are fixed to the ceiling using magnets; the 3 motes outside are placed in a water-tight boxes. Thanks to the "peel-and-stick" nature of this low-power wireless technology, deployment takes less than an hour.

In the Smart Agriculture deployment, we use four types of SmartMesh IP devices. Inside the orchard, 2 DC9018 boards feature an external antenna, 16 DC9003 boards a chip antenna. We deploy 3 long-range repeaters outside the orchards to connect the network to the gateway, located some 300 m away. In the Smart Building deployment, we use 2 types of SmartMesh IP devices: 11 DC9003 boards (chip antenna), 1 DC9018 board (external antenna). For both deployments, the gateway is composed of a Raspberry Pi single-board computer connected to a DC2274 SmartMesh IP manager over USB. All boards are off-the-shelf.

The SmartMesh IP network implements the IEEE802.15.4e standard [2], which includes a channel-hopping mechanism to reduce the impact of multi-path fading and external interference. This allows the network to be highly reliable, stable, and extremely low power [8, 9]. Each mote produces a temperature value every 30 s, and network statistics every 5 min. We extract 3 months of data for each deployment, resulting in over 4 million temperature values, and more than 350,000 network statistics for each deployment.

The goal of this article is to analyze the network statistics over the 3-month periods, precisely assess the performance of both networks, and contrast/compare them. This article makes the following contributions:

- We confirm that the SmartMesh IP network exhibits years of battery lifetime and wire-like reliability in both cases;
- We show that channel hopping causes the network topology to be very stable, with $\leq$15 link changes on average per day;
- Contrary to popular belief, we show that links in the networks are symmetric, i.e. they exhibit the same signal strength in both directions of the same link;
- We conclude that SmartMesh IP is a perfectly suitable IoT technology for the Smart Agriculture and Smart Building domains.

The remainder of this article is organized as follows. Section 2 describes the types of network statistics, and the dataset of statistics collected over the 3 month periods. Section 3 presents results that confirm assumptions about what we can expect for real-world SmartMesh IP deployment. Section 4 presents not so intuitive results about link symmetry and network stability. Finally, Section 5 concludes this article and discusses further improvements.

2. Statistics Collected

The Smart Agriculture network is deployed in a peach orchard in Junín, 45 km South-East of Mendoza in Western Argentina. No other electronic devices are present in the field. Farmers work inside the field with heavy machinery for 1-2 h every 20 days approximately. In the region, air temperature ranges between -9 C in winter (May-October) to $+38$ C in summer (November-April).

type	Smart Agriculture	Smart Building
mote_create	133	85
path_create	4,098	1,403
path_delete	3,653	1,325
HR_DEVICE	132,758	154,698
HR_DISCOVERED	87,737	152,641
HR_NEIGHBORS	140,897	128,072

Table 1: The number of statistics collected over the 3 month periods.

Because of the sunny weather, day/night temperature swings of 10+ C are not uncommon in winter.

The Smart Building network is deployed in the Inria offices (a research institute) in Paris, France. It is deployed in a typical 5-story office building, in which semi-permanent walls separate the offices which are arrange around a concrete core which houses the elevators. Several wireless technologies operate in the same building, including Wi-Fi, Bluetooth and other IEEE802.15.4-based networks. Around 200 people work in that office with lots of activity, mainly during office hours.

Each device in the network produces both sensor data and network statistics. Network statistics can be separated in Events and Health Reports messages. *Event* messages are non-periodic notifications the network sends when a network event happens (e.g. a mote joins/leaves the network, a link is created/deleted). *Health Report* (HR) messages are sent periodically by each mote; they contain counters and statistics about that mote. HRs are used to assess the overall health of the network.

Table 1 summarizes the number of events and HRs gathered during the 3 month periods of both deployments. In the remainder of this section, we detail the meaning of each of the statistics.

`mote_create`. Each node in a SmartMesh IP network periodically sends beacons to announce the presence of the network. When a mote wants to join a network, it listens for those beacons. Once it has heard a beacon, the new mote starts a security handshake with the network. During that handshake, the SmartMesh IP manager sends a `mote_create` event notification over its serial port. This is the event we log[1]. It contains, among other information, the association between the newly-joined device's 8-byte MAC address and its 2-byte `moteId`.

`path_create` and `path_delete`. In SmartMesh IP terminology, a "path" is the link-layer resource that allows two neighbor nodes to communicate[2]. Each

[1]Normally, each mote generates a single `mote_create` event. Due to power issues at the manager side, the network restarted a couple of times and new events were created.

[2] In more classical networking terminology, this is often referred to as a "link". We use the terms "path" and "link" interchangeably in this article.

time a mote starts communicating with a new neighbor (e.g. its routing parent), a `path_create` event is produced. Similarly, each time a mote *stops* communicating with a neighbor (e.g. it changes routing parent), a `path_delete` event is produced. We log both messages.

`HR_DEVICE`. Each network device produces a `HR_DEVICE` every 15 min. This health report contains counters/statistics internal to the mote, such as its current battery voltage, temperature, or total number of messages sent.

`HR_DISCOVERED`. SmartMesh IP nodes continuously monitor their surroundings to discover neighbor nodes. Every 15 min, each node produces an `HR_DISCOVERED` health report that contains the list of "discovered" neighbors, and the associate signal strength it heard them at. These discovered neighbors can potentially be used in the future as neighbors the node communicates with.

`HR_NEIGHBORS`. Two nodes are neighbors when link-layer resources are installed for them to communicate. The neighbors of a node are a subset of the discovered neighbors. Every 15 min, each note generates an `HR_NEIGHBORS` health report that contains its list of neighbors. These messages also specifies per-neighbor counters, such as the number of link-layer retransmissions.

After 3 months of operation, we have collected 369,276 and 386,929 network statistics in the Smart Agriculture and Smart Building deployment respectively (see Table 1). The goal of the next section is to present the main results from analyzing this information. We group these results in two categories. "Intuitive" results (Section 3) are results that confirm the performance expected from a SmartMesh IP network. "Not so intuitive" results (Section 4) are results that we believe go against popular belief. This classification is necessarily subjective.

Possibly due to power line failure at the network manager side, the network experienced some restarting. For this reason, some analysis presented in the next sections are done in shorter period. As a side effect, this allows us to verify the network formation and joining process.

3. Intuitive Results

Previous publications [7, 8, 9, 10] underline the performance of TSCH networks in general, and SmartMesh IP in particular. Standardization work in the IETF 6TiSCH working group[3] around TSCH networks further illustrates the move of the industry towards this type of networking technology. While we generally expect good performance from the network, this section verifies that this is the case, on the commercial SmartMesh IP implementation. We start by looking at two physical-layer metrics: RSSI vs Distance (Section 3.1) and PDR vs. RSSI (Section 3.2). While these have no dependency on TSCH (the type of medium access), they allow us to verify the overall connectivity in the network. We then look at key performance indicators: end-to-end reliability (Section 3.3) and network lifetime (Section 3.4).

[3] `https://tools.ietf.org/wg/6tisch/charters`

3.1. RSSI vs. Distance

The Friis transmission model [5] gives the relationship between the Received Signal Strength (RSSI)[4] in free space. While it does *not* apply directly to our real-world deployment, we note in Fig. 6 that the individual RSSI values are located between the Friis model, and the Friis model offset by -40 dB. This corroborates the results from [11].

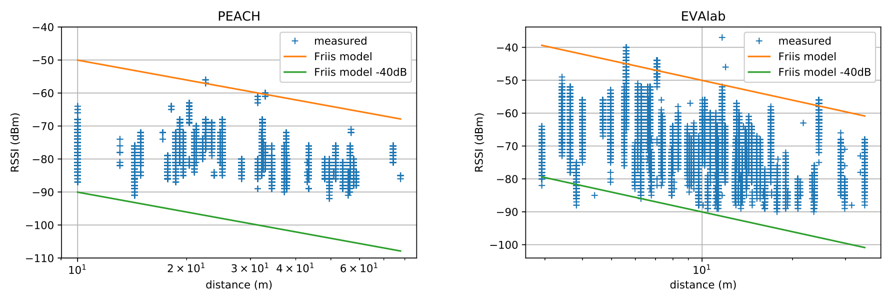

Figure 6: RSSI measurements are roughly located between the Friis model and the Friis model shifted by -40 dB.

3.2. Wireless Waterfall

Due to the inherent physical unreliability of the radio medium, it is impossible to know if a future transmission will be successful or not. The Packet Delivery Ratio (PDR) is the portion of successful link-layer transmissions over the total number of link-layer transmission attempts. A failed attempt means that the link-layer frame needs to be re-transmitted; it does *not* mean the packet is lost. Over a period of 3 months, 140,897 `HR_NEIGHBORS` messages are collected in the PEACH deployment and 128,072 in the EVAlab deployment. These contain, for a given node, the number of link-layer transmission attempts and successes to each of its neighbors. We remove the portion of neighbors with no transmission and keep only the DC9003 motes, resulting in a total of 69,643 messages (approx. 49% from the total number of `HR_NEIGHBORS`) for the PEACH deployment and a total of 93,135 messages (approx. 73%) for the EVAlab deployment.

Fig. 7 plots the PDR and the RSSI of these 69,643 and 93,135 messages. For readability, we also plot the average/deviation of the data for a given RSSI value. Because of its shape, this is known as the "waterfall plot".

For the PEACH deployment, above -85 dBm, the PDR of the link is very good ($> 95\%$). Below that value, the PDR rapidly degrades, indicating that, on these links, frequent retransmissions happen. For the EVAlab deployment,

[4] Strictly speaking, the RSSI is the Received Signal Strength *Indicator*, a value returned by radio chip. Because of its prevalence in low-power wireless literature, we use it RSS and RSSI interchangeably.

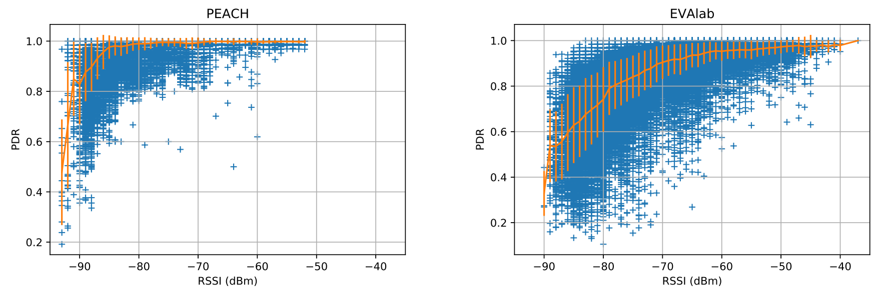

Figure 7: The PDR/RSSI "waterfall" plot. The EVAlab curve is shifted right indicating an interference-prone environment.

	PEACH	EVAlab
reliability (Arrived/Lost)	100% (693,844/0)	100% (431,193/0)
average PDR (Transmit/Fails)	95% (4,405,569/258778)	87% (19,807,535/2,488,149)
latency	700 msec	Not measured

Table 2: The overall network performance in the 15-25 July 2016 period (PEACH) and the 12/11/16 and the 12/02/17 (EVAlab).

the PDR starts to degrade at $-60\ dBm$. The device manufacturer documentation [4] indicates that a path is considered as "bad" when:

- RSSI$> -80\ dBm$ and PDR$< 50\%$
- RSSI$> -70\ dBm$ and PDR$< 70\%$

This is not the case in any of the two deployments.

A *waterfall plot* either shifted right with very few paths below $-70\ dBm$, or with a non-constantly decreasing curve would be an example of interference-prone environment. This is not the case for the PEACH deployment, meaning that the SmartMesh IP network is not experiencing high levels of interferences from co-located wireless devices. This is the case for the EVAlab deployment, meaning that the SmartMesh IP network is experiencing external interferences. Those results correspond to the environment described in Section 1 as other concurrent technologies are present in the building.

3.3. End-to-End Reliability

We expect the SmartMesh IP network to offer wire-like reliability. Table 2 confirms that this is the case. It presents statistics gathered over July 15-25 2016 period in the PEACH orchard and from the 12th of November 2016 to the 12th of February 2017 in the EVAlab.

It shows that, as none of the 693,844 and 431,193 packets generated in the networks was lost, the end-to-end reliability is 100%. The average PDR over all the links is very high (95% and 87%), indicating that the nodes are deployed close enough to one another. Finally, the average latency over all nodes is 700 ms for the PEACH deployment. These results are very similar to the very initial results presented in [7], indicating no degradation in performance of the SmartMesh IP network over the 3 month operation.

3.4. Network Lifetime

Each device is powered by a pair of Energizer L-91 AA batteries. These contain a nominal 3134 mAh of charge, or 2821 mAh when accounting for a 10% decrease due to manufacturing differences. A SmartMesh IP node contains a "charge accounting" feature in which it tracks the amount of charge is has been drawing from the battery. Each mote reports this number every 15 min as a field in its `HR_DEVICE` health report. This number allows us to predict the lifetime of the device.

Table 3 shows charge consumed by the motes over the two 3 month periods, as well as the portion of the battery this represents. Assuming the same energy consumption rate, we can extrapolate the lifetime. The nodes with the longest lifetime (8 years) are all leaf nodes as we can see from Fig. 4. Since it does not have to relay data from any children, it is normal that this node consumes very little. The node with the shortest lifetime is `30-60-ef` and has 4 years of lifetime, it is normal as this node has an external antenna and relays a lot of data. This shows the ultra-low power consumption of the SmartMesh IP network.

4. Not so Intuitive Results

Results from Section 3 are "intuitive" is that they corroborate previous measurements [7] or confirm theoretical/lab results [8, 9, 10]. This section presents results which we believe go against popular belief. This classification is necessarily subjective.

In Section 4.1, we show that links are, in fact, symmetric. In Section 4.2, we show that, through the use of TSCH, the low-power wireless topology is, in fact, extremely stable.

4.1. Link (A)Symmetry

Motes report the average RSSI value of the packets received from each neighbor in their `HR_NEIGHBORS` health reports. Because the network uses channel hopping, these reported RSSI values are also averaged over 15 IEEE802.15.4 frequencies [1]. In this section, we use the term "RSSI" to denote the average RSSI over 15 frequencies.

A common assumption is that links between neighbor low-power wireless devices are hugely asymmetric. That is, on a link between nodes A and B, A receives B's link-layer frames with an RSSI very different from the frames B receives from A. Numerous routing protocols (often standardized [3]) reuse that assumption and start with a costly step of filtering out asymmetric links.

MAC	charge consumed	lifetime
30-60-ef	695 KC (6.8%)	4 years
38-0f-66	461 KC (4.5%)	6 years
3f-f8-20	380 KC (3.7%)	8 years
3f-fe-87	549 KC (5.4%)	5 years
3f-fe-88	718 KC (7.1%)	4 years
58-32-36	311 KC (3.1%)	7 years
60-01-f8	387 KC (3.8%)	8 years
60-02-1b	371 KC (3.7%)	8 years
60-02-4b	406 KC (4.0%)	7 years
60-03-82	395 KC (3.9%)	8 years
60-05-5f	386 KC (3.8%)	8 years
60-05-69	509 KC (5.0%)	6 years
60-05-78	364 KC (3.6%)	8 years
60-05-ab	381 KC (3.8%)	8 years
60-06-27	422 KC (4.2%)	7 years
60-08-d5	432 KC (4.3%)	7 years

(a) PEACH

MAC	charge consumed	lifetime
38-03-dd	459 KC (5.8%)	4 years
58-e9-ca	411 KC (5.2%)	5 years
58-e9-cb	407 KC (5.1%)	5 years
58-eb-5b	423 KC (5.3%)	5 years
58-eb-64	322 KC (4.1%)	6 years
58-eb-67	468 KC (5.9%)	4 years
58-eb-69	243 KC (3.1%)	6 years
58-f3-17	357 KC (4.5%)	5 years
58-f4-f8	402 KC (5.1%)	5 years
58-f5-23	416 KC (5.3%)	5 years
58-f5-3c	412 KC (5.2%)	5 years
58-f5-58	387 KC (4.9%)	5 years
58-f8-63	198 KC (2.5%)	7 years
58-f8-78	233 KC (2.9%)	6 years
58-f8-8f	439 KC (5.5%)	4 years
58-f9-c4	325 KC (4.1%)	6 years

(b) EVAlab

Table 3: Per-node power consumption and associated expected lifetime when powered by a pair of AA batteries.

We look at the link statistics between the 18th of June 2016 and the 4th of July 2016 (16 days) in the PEACH deployment and between the 12th of N. The sample contains 411,132 `HR_NEIGHBORS` messages received from 14 DC9003 nodes (same hardware). During that period, 21 links are active with at least 250 transmissions for each link. For each of those links, we compute the difference between average RSSI in each directions. Results are presented in Fig. 8.

Fig. 8 shows that the RSSI difference never exceeds a couple of dB. Looking at Fig. 7, this translates into a handful of percentage points difference in PDR only. This means the links can be considered symmetric. This result is in-line with the physical phenomenon that the signal traveling from A to B undergoes the same attenuation as that from B to A. This result would *not* hold if the neighbor radios had a different transmit power or sensitivity. That being said, discussions on link symmetry at the routing layer is largely artificial, as any “good” medium access control (MAC) protocol uses link-layer acknowledgments.

4.2. Network Stability

Wireless in unreliable in nature. It is normal that some wireless links interconnecting motes “come and go”. That is, links that have been performing well (e.g. PDR¿90%) can suddenly disappear (e.g. $PDR < 10\%$). Similarly, nodes that were not able to communicate can suddenly hear one another perfectly.

The question, however, is what time scale is considered. Early academic work on low-power wireless [6] has looked at the “burstiness” of the wireless

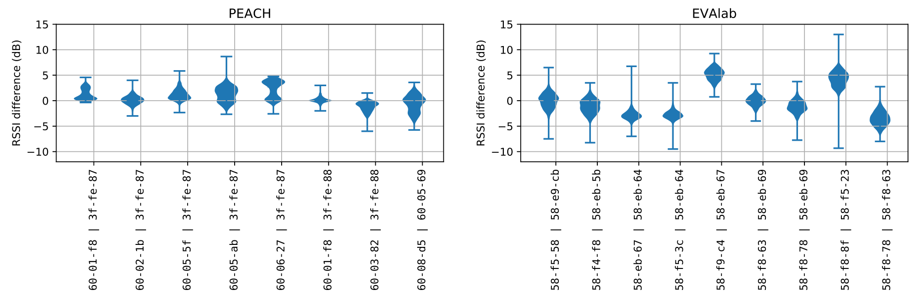

Figure 8: The difference in RSSI between the two directions of 7/12 wireless links in the PEACH/EVAlab deployment. The violin plots show the distribution of the value and the standard deviation.

links, i.e. changes over the course of 10-1000's ms. Some follow-up work has taken the assumption that wireless links are so unstable that only a reactive routing approach works. In this section, we infirm this statement by looking at the stability of the network.

In particular, we look at the `path_delete` and `path_create` events. These are generated each time a node adds/deletes a neighbor to communicate with, which happens for example when the routing topology changes (see Section 2). The number of `path_delete` and `path_create` events is a direct measurement of the network stability. Note that we removed the nodes that does not respect the Dust requirement of having at least two parents to associate with (one node in the PEACH deployment and three in the EVAlab one). Due to the lack of second parent, the nodes were producing over 20 times the amount of messages than all the other nodes assembled.

Fig. 9 shows the number of `path_delete` and `path_create` events per day, over a 16 days (PEACH) and 2 months (EVAlab). For reference, the total number of links in the network is also depicted. There are less than 5 `path_delete` or `path_create` events *per day* in the entire PEACH network and less than 15 `path_delete` or `path_create` events *per day* in the EVAlab. This means that links, once established, remain useful for days/weeks at a time, and that the network is extremely stable. The reason why there are more events per day in the EVAlab deployment is not studied here.

This stability can largely be attributed to the use of channel hopping. Changing frequency for each packet is known to efficiently combat multi-path fading and external interference [9], the major causes of instability. It does not contradict the findings of [6], it just means that link-layer retransmissions can efficiently cope with link burstiness, and that the multi-hop topology can remain very stable.

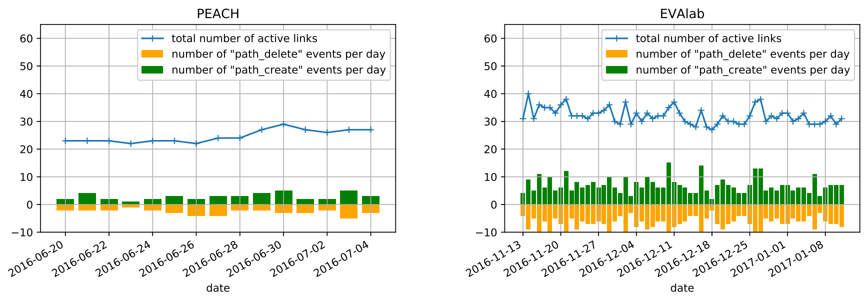

Figure 9: Network stability: the number of `path_create` and `path_delete` events generated per day over a 16 days (PEACH) and two months (EVAlab). The top line shows the total number of active links.

5. Conclusion

This article analyzes the network statistics generated by two low-power wireless mesh networks deployed in real-world conditions. The first deployment in peach orchard in Argentina of 21 nodes produced 369,276 statistics over the course of 3 months. The second deployment in an office building in Paris of 17 nodes produced 386,929 statistics over the course of 3 months

We use a "waterfall" plot to show that the two networks are subject to different amount of interferences from other wireless devices deployed in the same area. The SmartMesh IP network delivers its exceptional performance, with 0 packets lost out of 693,844 (PEACH) and 431,193 (EVAlab) received (100% reliable) and 4-16 years of battery lifetime on a pair of commercial AA batteries.

While it is often assumed that wireless links are asymmetric, we show to the contrary that the difference in RSSI averaged over 15 IEEE802.15.4 channels does not exceed a handful of dB. We show that the network is extremely stable, with less than 5 links being added or deleted per day in an outdoor environment and 15 links being added or deleted per day in an indoor environment.

We attribute this performance to the use of Time Synchronized Channel Hopping (TSCH) technology at the heart of the SmartMesh IP products.

[1] 802.15.4-2011: IEEE Standard for Local and metropolitan area networks. Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs), 5 September 2011.

[2] 802.15.4e-2012: IEEE Standard for Local and metropolitan area networks–Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 1: MAC sublayer, 16 April 2012.

[3] T. H. Clausen and P. Jacquet. Optimized Link State Routing Protocol (OLSR), October 2003.

[4] Linear Technology. *SmartMesh IP Application Notes*, 2015.

[5] S. R. Saunders and A. Aragón-Zavala. *Antennas and Propagation for Wireless Communication Systems*. Wiley-Blackwell, 2nd edition, 2007.

[6] K. Srinivasan, M. A. Kazandjieva, S. Agarwal, and P. Levis. The β-factor: Measuring Wireless Link Burstiness. In *Conference on Embedded Network Sensor Systems (SenSys)*, pages 29–42, Raleigh, NC, USA, 2008. ACM.

[7] T. Watteyne, A. L. Diedrichs, K. Brun-Laguna, J. E. Chaar, D. Dujovne, J. C. Taffernaberry, and G. Mercado. PEACH: Predicting Frost Events in Peach Orchards Using IoT Technology. *EAI Endorsed Transactions on the Internet of Things*, June 2016.

[8] T. Watteyne, S. Lanzisera, A. Mehta, and K. S. Pister. Mitigating Multipath Fading through Channel Hopping in Wireless Sensor Networks. In *IEEE International Conference on Communications (ICC)*, pages 1–5, Cape Town, South Africa, 23-27 May 2010. IEEE.

[9] T. Watteyne, A. Mehta, and K. Pister. Reliability Through Frequency Diversity: Why Channel Hopping Makes Sense. In *International Symposium on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks (PE-WASUN)*, pages 116–123, Tenerife, Canary Islands, Spain, 26-30 October 2009. ACM.

[10] T. Watteyne, J. Weiss, L. Doherty, and J. Simon. Industrial IEEE802.15.4e Networks: Performance and Trade-offs. In *International Conference on Communications (ICC), Internet of Things Symposium*, London, UK, 8-12 June 2015. IEEE.

[11] S. Zats. Wireless Sensor Networks Scaling and Deployment in Industrial Automation. Master's thesis, University of California, Berkeley, 13 May 2010.