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ABSTRACT. *In the context of increasing developments of home, building and city automation, our view of the future building networking infrastructure places PLC as the central point. Thanks to the design of converging IPv6 networking layers, we show that merging PLC with existing WSN is possible even in very constrained networking devices to provide a significant increase for lifetime, reliability, and routing capabilities.*

RÉSUMÉ. *Dans le contexte de l' évolution de l'automatisation des maisons, des bâtiments et des villes, notre vision des futures infrastructures de communication place le réseau CPL comme le point central. Grâce à la convergence des couches réseau autour d'IPv6, nous montrons que l'intégration du CPL avec les réseaux de capteurs sans fil est possible même dans des dispositifs très contraints pour offrir une augmentation significative de leur durée de vie, de leur fiabilité et de leurs capacités de routage.*

KEY WORDS: *PLC, WSN, 802.15.4, 6LoWPAN, IPv6, RPL, Home Automation, Building Automation.*

MOTS-CLÉS : *CPL, Réseaux de Capteurs, 802.15.4, 6LoWPAN, IPv6, RPL, GTB, GTC.*

1. Related Work

To our knowledge, there is just a few work on merging constrained devices running on different media, mostly because most of sensor networks are considered to run over 802.15.4 only. To tackle this, we proposed an adaptation of the 802.15.4 standard over PLC, to enable interoperability in [CTGC10]. Thus, PLC is able to leverage on the 6lowpan adaptation [MKHC07] and benefits from the large amount of work of the WSN community [HC08] [DVA04]. This new media offers new perspectives and our work tries to fulfill the gap with Low power and Lossy Networks (LLNs). According to [LTDH09], we focus on the Routing Protocol for LLNs (RPL) which fulfill all the requirements induced by LLNs in a media agnostic manner.

2. Motivations

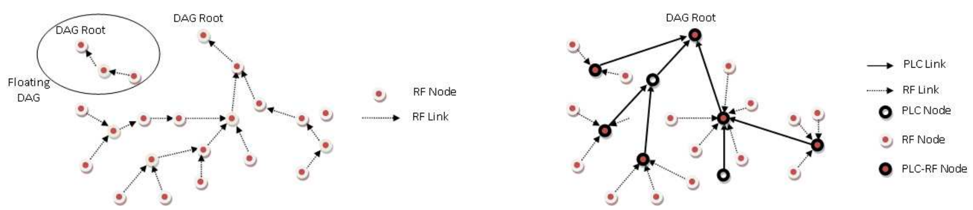
First, mixing PLC with WSN in the same topology increase global lifetime. For battery powered nodes, lifetime is related to power consumption and is the biggest challenge to achieve [ST09]. The most used technique to reduce energy consumption are duty cycling protocols based on periodic wake-up periods [vDL03]. In addition, we proposed to carry most of the traffic over PLC, which is a non constrained by energy. Second, offering an alternative media like PLC in a network increase significantly path diversity and may cope better with link quality variations. PLC and RF are not sensitive to the same disturbers, so a hybrid network provide a more reliable path across these media. Third, PLC may reach farther than 802.15.4, and reduced the number of hops to reach a distant node, thus reduce forwarding. In a building context, one hop over PLC may join multiple floors whereas wireless links may be stopped by slabs. Fourth, PLC increase connectivity and may reach zones that are unreachable via wireless links, in particular in sparse networks.

3. Architecture

Our architecture can be composed of RF-only, PLC-only or RF-PLC devices. The PLC benefit in a WSN topology is illustrated in figure 1 and table 1. In table 1, **A** reflects the maximum number of forwarding to reach a node in the DAG. PLC reduces the number of maximum forwarding. **B** reflects the amount of traffic a battery operated device has to forward. PLC reduces this load to almost no forwarding, resulting in a better energy preservation and lifetime maximization. **C** reflects the average length of paths in the DAG. PLC reduces this average because of path diversity enhancement. **D** corresponds to the time when the first node in the network dies. This reflects the lifetime expansion obtained with PLC. For the RF DAG case, the first node under the root has the largest sub-DAG with 17 nodes. **E** reflects network partitioning. PLC increases reliability with a new path to reach these nodes.

4. Networking performances of PLC

Figure 2 show the measured performances of a real and a simulated PLC network implementing the network stack presented using Contiki. The Real test bed was a 2 floors laboratory, composed of 25 rooms submitted to real life activity. PLC nodes were implemented in the Cooja simulator.



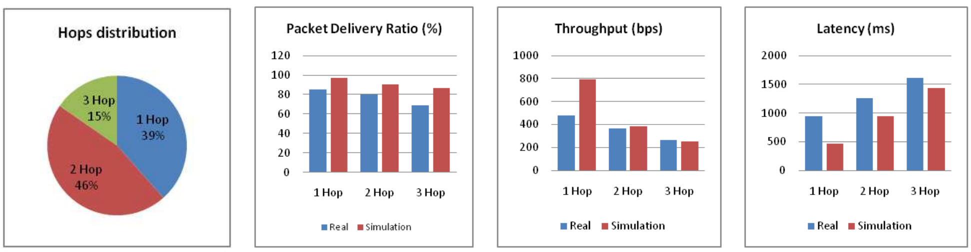
(a) RF-Only DAG (b) Heterogeneous DAG

Figure 1. *Comparison of RF and Heterogeneous DAG*

		RF DAG	PLC + RF DAG
A	Depth of the DAG	6	3
B	Average Hops over RF Nodes	3.78	1
C	Average Hops in the entire DAG	3.78	2.26
D	Estimated Lifetime of the DAG	T	17*T
E	Number of Unreachable Nodes	3	0

Table 1. *DAG Features comparison*

In our experiments we always succeed to reach all the 6 PLC nodes through a 3 hops maximum path in all rooms tested from the border router location. This points out reliability, connectivity and forwarding reduction potential of PLC. Performances of the PLC network (PDR, Throughput and Latency) decrease with path length (number of hops). Throughput is less impacted by real PLC links because it is only computed for successful transmissions. Latency performances show that real PLC links induce many more link layer retries on real PLC networks. In the simulation, even with ideal



(a) Hops Repartition (b) Packet Delivery Ratio (%) (c) Throughput (bps) (d) Latency (ms)

Figure 2. *Performances of real and simulated PLC network*

Pros	Cons
Increased lifetime	Increased average latency
Increased path diversity	Decreased average throughput
Reduced forwarding	
Increased reliability	

Table 2. *PLC pros and cons in WSN*

links, 100% PDR is not reached because of collisions with traffic control messages in our context of RPL/6LoWPAN routing.

5. Conclusion and Perspectives

According to table 2, the value of merging PLC with existing WSN depends on the objective. It is clear that PLC integration is a benefit for lifetime and path diversity, and may be useful to reduce path length and increase reliability. But a tradeoff has to be made regarding network performance impact. Though, because lifetime is the biggest issue with WSN, we strongly believe in PLC benefit. It is also important to note that all presented cons may be balanced by further PLC technology developments. Future work concerns an implementation of the multi physical stack proposed. Indeed, the routing metrics choice will have a big impact and will be carefully studied.

6. References

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