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Arch Rock IP/6LoWPAN Overview: An IPv6 Network Stack for Wireless Sensor Networks

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Bringing Wireless Sensor Networks into the IP Fold

By natively supporting the Internet Protocol (IP), sensor nodes can communicate using IP-based protocols such as ICMP, UDP, and TCP. In this scenario, applications simply become IP services and network management can be performed using familiar tools such as ping and traceroute. Native IP support also allows sensor nodes to communicate directly with any other IP-enabled nodes without a heavyweight and stateful translation gateway in between. Instead, a simple router connects the two worlds by routing packets between IEEE 802.15.4, Ethernet, and WiFi interfaces. Arch Rock IP/6LoWPAN is an IPv6-compliant network stack optimized for wireless sensor networks. It is based on IETF 6LoWPAN (RFC 4944), the first industry-standard solution for IP communication over low-power wireless personal-area networks.

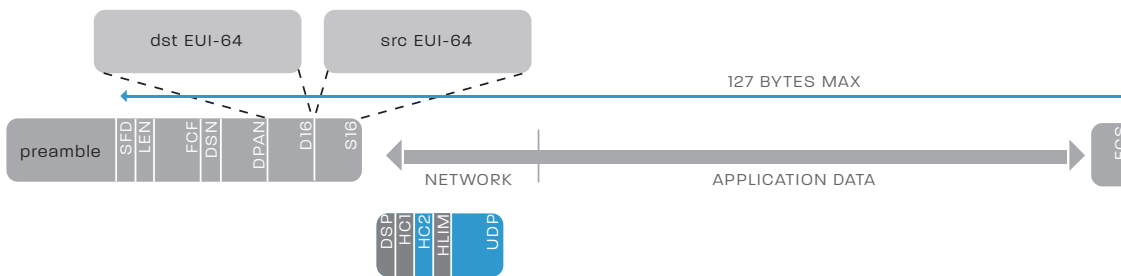
Note: IP networks do not require connectivity with the Internet; they may occasionally connect to and communicate with other Internet-connected hosts, or may never connect at all. IP/6LoWPAN, no exception to this model, supports both connected and disconnected operation.

tion from the IP header. In the simplest case, IP addresses and payload length are inferred from the link header, allowing compression of a 40-byte IPv6 header down to two bytes. To support more complex communication, 6LoWPAN follows a “pay-as-you-go” model where overhead is increased only when needed. For communication with devices outside the 6LoWPAN network, larger IP addresses are included.

Reliable Routing

The routing function within the IP/6LoWPAN network resides above the IP layer, making each sensor network node both an IP router and an end point. By routing above IP, each 802.15.4 hop becomes an explicit IP hop, creating IP-level visibility into the network topology. The standard Arch Rock routing protocol utilizes a Rendezvous Point (RP), typically the 6LoWPAN router. Based on a distance-vector protocol, the routing protocol is responsible for picking a default route to the RP. To guard against variations in wireless connectivity, two successor default routes are maintained and used whenever the primary route fails. Thus each node forms a triply-redundant path for reliable communication with the RP. In choosing routes, nodes choose next hops that minimize the cost to

Figure 1. 6LoWPAN Encoding (Single Hop)



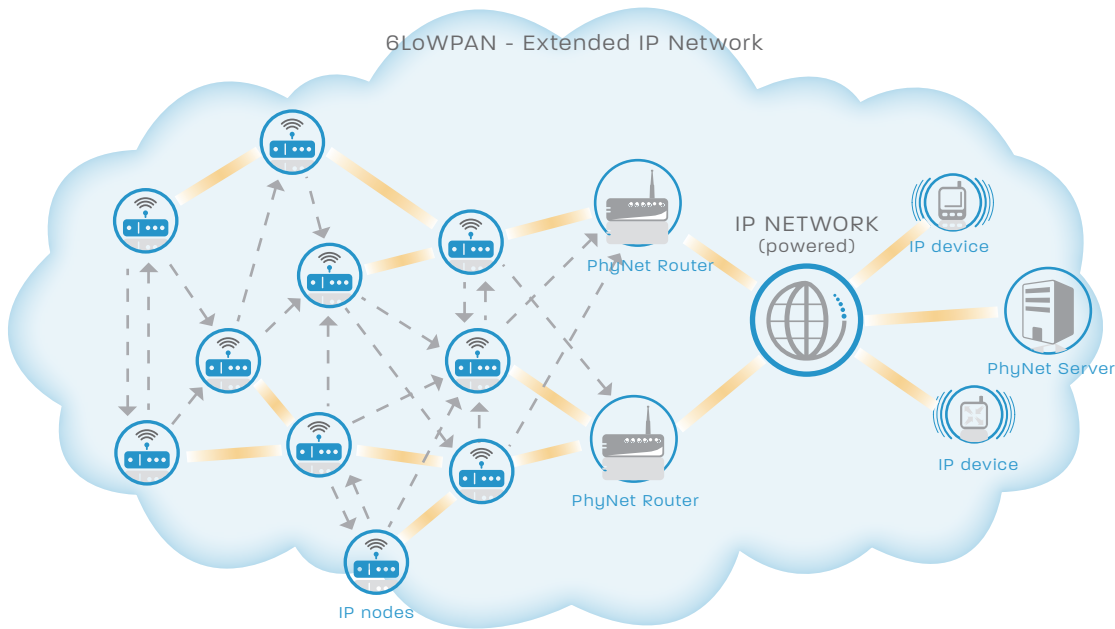
6LoWPAN Standard Packet Formats

Unlike traditional IP hosts, wireless sensor networks operate with strict resource constraints. IP packets contain large addresses and headers and usually large data payloads, which may not fit within the small 127-byte MTU (maximum transmission unit) of 802.15.4. To support efficient transmission of IP packets over IEEE 802.15.4, Arch Rock IP/6LoWPAN is based on the IETF 6LoWPAN standard [1]. 6LoWPAN provides an adaptation layer that compresses IP headers to shrink packets. The key concept is to infer information from the link header and remove any redundant or unneeded informa-

tion from the IP header. In the simplest case, IP addresses and payload length are inferred from the link header, allowing compression of a 40-byte IPv6 header down to two bytes. To support more complex communication, 6LoWPAN follows a “pay-as-you-go” model where overhead is increased only when needed. For communication with devices outside the 6LoWPAN network, larger IP addresses are included.

the RP. To compute the cost metric, link statistics are gathered from explicit beaconing while the network is forming, and inferred from data traffic in the steady state. This “adaptive beaconing” approach keeps the network robust in volatile environments while minimizing control overhead in stable conditions. Once a path is established, nodes inform the RP of their location, allowing the RP to route packets back to individual sensor nodes.

Figure 2. Arch Rock Triply-Redundant IP/6LoWPAN Network



Power-Efficient, Responsive Media Management

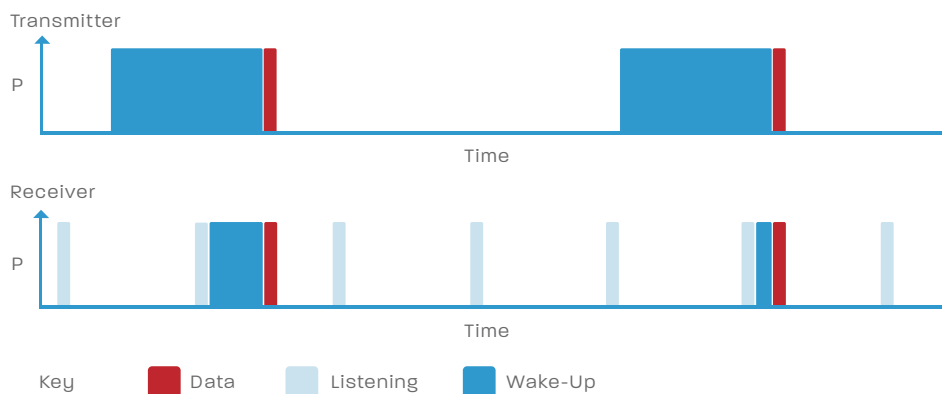
Below the IP/6LoWPAN layer is Arch Rock's low-power link layer that operates on IEEE 802.15.4 radios. The link layer implements a protocol based on sampled listening that does not require scheduling, synchronization, or any build-up of context before IP packets are sent to neighboring nodes. Because a node can choose to unicast to a neighboring node or even broadcast to all neighbors at any time, without waiting for specific time-slots, an illusion of "always on" is created. This allows the network to have rapid response times, critical for network management and mobility applications.

Other approaches that rely on scheduled communication require that a node remain in a high-power state until it can synchronize with a global time base and insert itself into the schedule. Even after doing so, the node must continually correct for synchronization errors and clock drift variations, setting a lower bound on

bandwidth and energy consumption. In contrast, Arch Rock's low-power link layer uses quick channel samples that do not require synchronization with other nodes. A transmitting node sends a series of wakeup packets, notifying the receiver(s) of the pending transmission. While each transmission carries extra overhead, transmissions in general are usually infrequent in low-power applications. Furthermore, pair-wise synchronization may be used to reduce transmission costs along commonly-used paths.

Arch Rock's low-power link layer allows additional optimizations through adjustments in sample period, shifting the energy burden between nodes. But by eliminating the need for synchronization and its associated costs, the link layer can be responsive, resilient and adaptive to changes in connectivity or traffic patterns. This is all done using the standard physical layer and packet formats as specified in IEEE 802.15.4-2006.

Figure 3. Illustration of Sampled Listening





Conclusion

Internet protocols provide a set of widely-used, open standards that deal with diverse and evolving suites of devices and networks. But only with the advent of 6LoWPAN have these protocols been scaled down sufficiently to be useful in wireless embedded networks. The 6LoWPAN breakthrough is to lever-

age the shared context that is typical for applications of this technology to obtain a very compact and efficient implementation of IP. Now low-power wireless devices on IEEE 802.15.4 radios can simply join WiFi and Ethernet devices, and others that make up the IP family.

About Arch Rock

Arch Rock is a pioneer in open-standards-based wireless sensor network technology. The company's products, which gather data from the physical world and integrate it into the enterprise IT infrastructure using IP networking and web services, are used in environmental monitoring, tracking and logistics, industrial automation and control. Arch Rock's founders, while at the University of California-Berkeley and Intel Research, did seminal research and development work on WSNs, creating three generations of wireless sensor nodes, mesh networking protocols, and the leading operating system for sensor networks. For more information, visit <http://www.archrock.com>.

[1] G. Montenegro, N. Kushalnagar, J. Hui, D. Culler. "Transmission of IPv6 Packets over IEEE 802.14 Networks", RFC 4944-September 2007.

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