3.1 **Applications of 6LoWPAN**

The reason why there are such a large number of technical solutions in the wireless embedded networking market is that the requirements, scale and market of embedded applications vary wildly. Applications can range from personal health sensor monitoring to large scale facility monitoring, which differ greatly. This is in contrast to PC information technology, which is fairly homogeneous and mainly aimed at home and office environments. The ideal use of 6LoWPAN is in applications where:

- embedded devices need to communicate with Internet-based services,
- low-power heterogeneous networks need to be tied together,
- the network needs to be open, reusable and evolvable for new uses and services
- scalability is needed across large network infrastructures with mobility.

Connecting the Internet to the physical world enables a wide range of interesting applications where 6LoWPAN technology may be applicable, for example:

1. home and building automation
2. healthcare automation and logistics

3.2 The 6LoWPAN Architecture

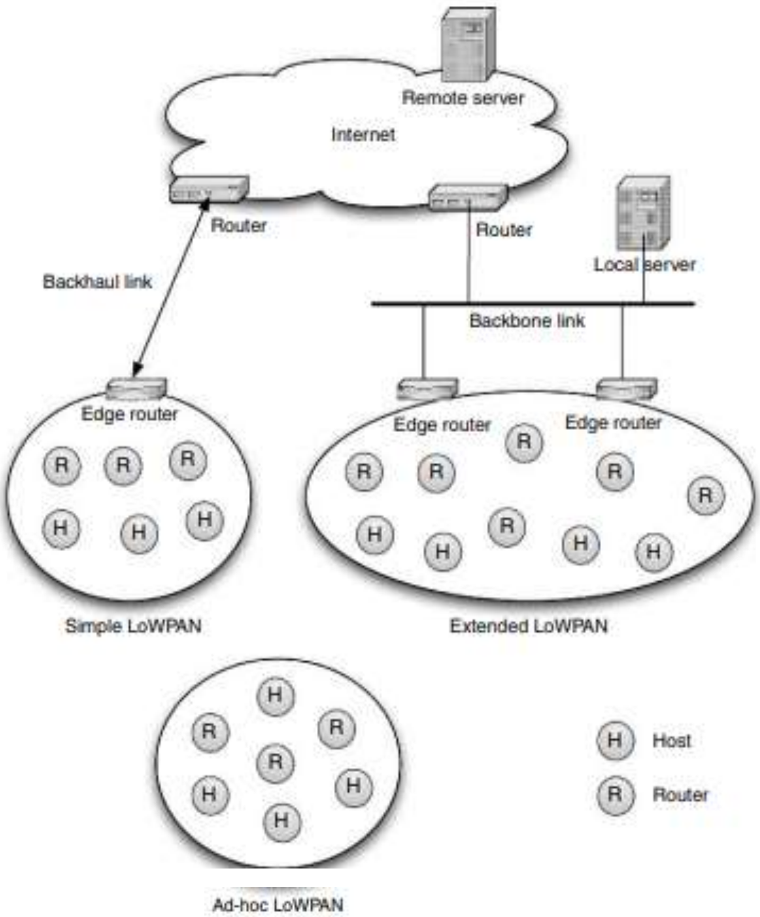

Fig 3.1 The 6LoWPAN architecture.

- The 6LoWPAN architecture is made up of low-power wireless area networks (LoWPANs)2, which are IPv6 stub networks. The overall 6LoWPAN architecture is presented in Figure 3.1. Three different kinds of LoWPANs have been defined:
  - Simple LoWPANs
  - Extended LoWPANs
  - Ad hoc LoWPANs.
- A LoWPAN is the collection of 6LoWPAN Nodes which share a common IPv6 address prefix (the first 64 bits of an IPv6 address), meaning that regardless of where a node is in a LoWPAN its IPv6 address remains the same.
- An Ad hoc LoWPAN is not connected to the Internet, but instead operates without an infrastructure. A Simple LoWPAN is connected through one LoWPAN Edge Router to another IP network. A backhaul link (point-to-point, e.g. GPRS) is shown in the figure, but this could also be a backbone link (shared). An Extended LoWPAN encompasses the LoWPANs of multiple edge routers along with a backbone link (e.g. Ethernet) interconnecting them.
- LoWPANs are connected to other IP networks through edge routers. The edge router plays an important role as it routes traffic in and out of the LoWPAN, while handling 6LoWPAN compression and Neighbor Discovery for the LoWPAN. If the LoWPAN is to be connected to an IPv4 network, the edge router will also handle IPv4 interconnectivity. Edge routers typically have management features tied into overall IT management solutions. Multiple edge routers can be supported in the same LoWPAN if they share a common backbone link.
- A LoWPAN consists of nodes, which may play the role of host or router, along with one or more edge routers. The network interfaces of the nodes in a LoWPAN share the same IPv6 prefix which is distributed by the edge router and routers throughout the LoWPAN. In order to facilitate efficient network operation, nodes register with an edge router. These operations are part of Neighbor Discovery (ND), which is an important basic mechanism
- of IPv6. Neighbor Discovery defines how hosts and routers interact with each other on the same link. LoWPAN Nodes may participate in more than one LoWPAN at the same time (called multi-homing), and fault tolerance can be achieved between edge routers. LoWPAN Nodes are free to move throughout the LoWPAN, between edge routers, and even between LoWPANs. Topology change may also be caused by wireless channel conditions, without physical movement. A multihop mesh topology within the LoWPAN is achieved either through link-layer forwarding (called Mesh-Under) or using IP routing (called Route-Over). Both techniques are supported by 6LoWPAN.

- Communication between LoWPAN Nodes and IP nodes in other networks happens in an end-to-end manner, just as between any normal IP nodes. Each LoWPAN Node is identified. by a unique IPv6 address, and is capable of sending and receiving IPv6 packets. Typically LoWPAN Nodes support ICMPv6 traffic such as "ping", and use the user datagram protocol (UDP) as a transport. the Simple LoWPAN and Extended LoWPAN Nodes can communicate with either of the servers through their edge router. As the payload and processing capabilities of LoWPAN Nodes are extremely limited, application protocols are usually designed using a simple binary format in a UDP payload.
- The main difference between a Simple LoWPAN and an Extended LoWPAN is the existence of multiple edge routers in the LoWPAN, which share the same IPv6 prefix and a common backbone link. Multiple LoWPANs can overlap each other (even on the same channel). When moving from one LoWPAN to another, a node's IPv6 address will change. A LoWPAN Edge Router is typically connected to the Internet over a backhaul link such as cellular or DSL [ID-6lowpan-nd]. A network deployment may also choose to use multiple Simple LoWPANs rather than an Extended LoWPAN on a shared backbone link, e.g. for management reasons. This is not a problem if there is low mobility between LoWPANs in the network, or the application does not assume stable IPv6 addresses for nodes.
- In an Extended LoWPAN configuration, multiple edge routers share a common backbone link and collaborate by sharing the same IPv6 prefix, offloading most Neighbor Discovery messaging to the backbone link [ID-6lowpan-nd]. This greatly simplifies LoWPAN Node operation as IPv6 addresses are stable throughout the Extended LoWPAN and movement between edge routers is very simple. Edge routers also handle IPv6 forwarding on behalf of the nodes. To IP nodes outside the LoWPAN, the LoWPAN Nodes are always reachable regardless of their attachment point in the Extended LoWPAN. This enables large enterprise 6LoWPAN infrastructures to be built, functioning similar to a WLAN (WiFi) access point infrastructure (but at layer 3 instead of layer 2).
- 6LoWPAN does not require an infrastructure to operate, but may also operate as an Ad hoc LoWPAN [ID-6lowpan-nd]. In this topology, one router must be configured to act as a simplified edge router, implementing two basic functionalities: unique local unicast address (ULA) generation [RFC4193] and handling 6LoWPAN Neighbor Discovery registration functionality. From the LoWPAN Node point of view the network operates just like a Simple LoWPAN, except the prefix advertised is an IPv6 local prefix rather than a global one, and there are no routes outside the LoWPAN.

The protocol stack

- A simple IPv6 protocol stack with 6LoWPAN (also called a 6LoWPAN protocol stack) is almost identical to a normal IP stack with the following differences.
- 6LoWPAN only supports IPv6, for which a small adaptation layer (called the LoWPAN adaptation layer) has been defined to optimize IPv6 over IEEE 802.15.4

- 6LoWPAN stack implementations in embedded devices often implement the LoWPAN adaptation layer together with IPv6, thus they can alternatively be shown together as part of the network layer.
- The most common transport protocol used with 6LoWPAN is the user datagram protocol (UDP), which can also be compressed using the LoWPAN format.
- The transmission control protocol (TCP) is not commonly used with 6LoWPAN for performance, efficiency and complexity reasons. The Internet control message protocol v6 (ICMPv6) is used for control messaging, for example ICMP echo, ICMP destination unreachable and Neighbor Discovery messages.
- Application protocols are often application specific and in binary format, although more standard application protocols are becoming available.
- Adaptation between full IPv6 and the LoWPAN format is performed by routers at the edge of 6LoWPAN islands, referred to as edge routers. This transformation is transparent, efficient and stateless in both directions. LoWPAN adaptation in an edge router typically is performed as part of the 6LoWPAN network interface driver and is usually transparent to the IPv6 protocol stack itself.

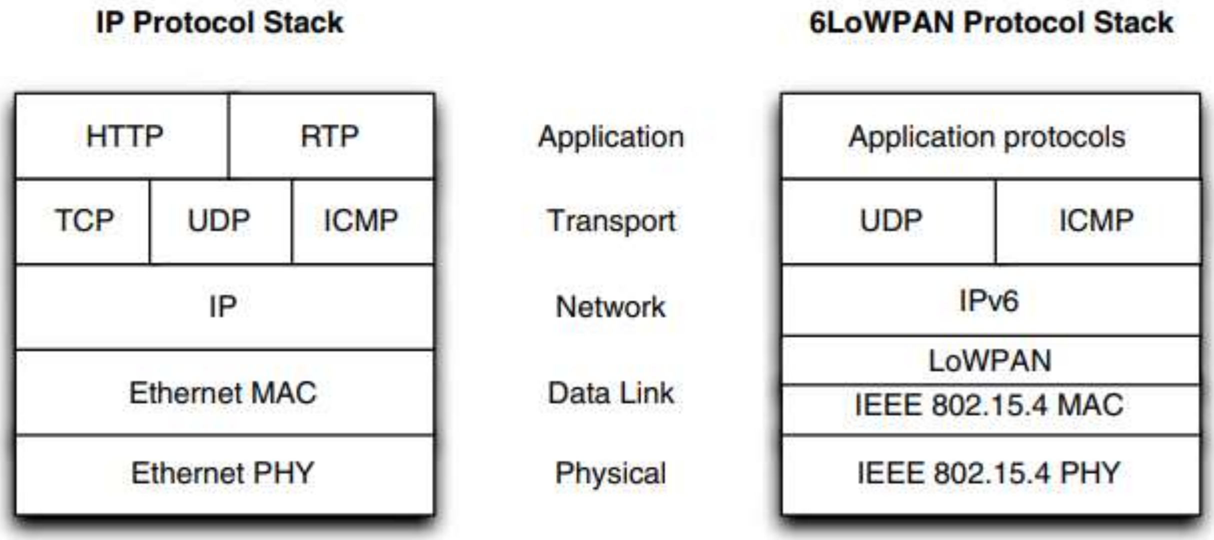

Fig 3.2 IP and 6loWPAN protocol stacks

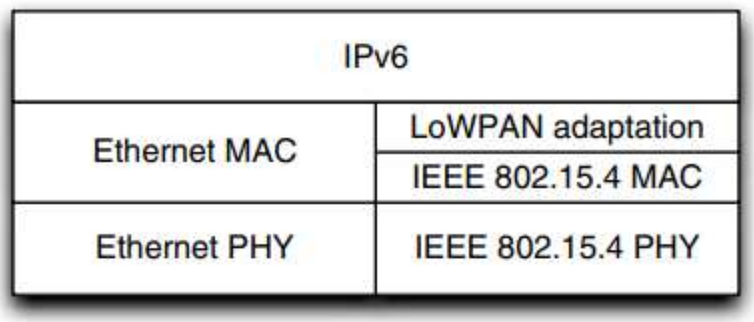

Fig: 3.3 IPv6 edge router with 6LoWPAN support.

- Figure 3.3 illustrates one realization of an edge router with 6LoWPAN support. See Section 6.4 for edge router implementation considerations. Inside the LoWPAN, hosts and routers do not actually need to work with full IPv6 or UDP header formats at any point as all compressed fields are implicitly known by each node.

Link layers for 6LoWPAN

- The most basic requirements for a link layer to support 6LoWPAN are framing, unicast transmission and addressing.
- Addressing is required to differentiate between nodes on a link, and to form IPv6 addresses which are then elided by 6LoWPAN compression.
- It is highly recommended that a link supports unique addresses by default (e.g. a 64-bit extended unique identifier [EUI-64]), to allow for stateless autoconfiguration.
- Multi-access links should provide a broadcast service. Multicast service is required by standard IPv6, but not by 6LoWPAN (broadcast is sufficient). IPv6 requires a maximum transmission unit (MTU) of 1280 bytes from a link, which 6LoWPAN fulfills by supporting fragmentation at the LoWPAN adaptation layer.
- A link should provide payload sizes at least 30 bytes in length to be useful (and preferably larger than 60 bytes). Although UDP and ICMP include a simple 16-bit checksum, it is recommended that the link layer also provides strong error checking.
- Finally, as IPsec may not always be practical for 6LoWPAN, it is highly recommended that links include strong encryption and authentication.

Addressing

- IPv6 addresses are typically formed automatically from the prefix of the LoWPAN and the link-layer address of the wireless interfaces. The difference in a LoWPAN is with the way low-power wireless technologies support link-layer addressing; a direct mapping between the link-layer address and the IPv6 address is used for achieving compression.
- IPv6 addresses are 128 bits in length, and (in the cases relevant here) consist of a 64-bit prefix part and a 64-bit interface identifier (IID).
- 6LoWPAN networks assume that the IID has a direct mapping to the linklayer address, therefore avoiding the need for address resolution. The IPv6 prefix is acquired through Neighbor Discovery Router Advertisement (RA) messages [ID-6lowpan-nd] as on a normal IPv6 link. The construction of

IPv6 addresses in 6LoWPAN from known prefix information and known link-layer addresses, is what allows a high header compression ratio.

Header format

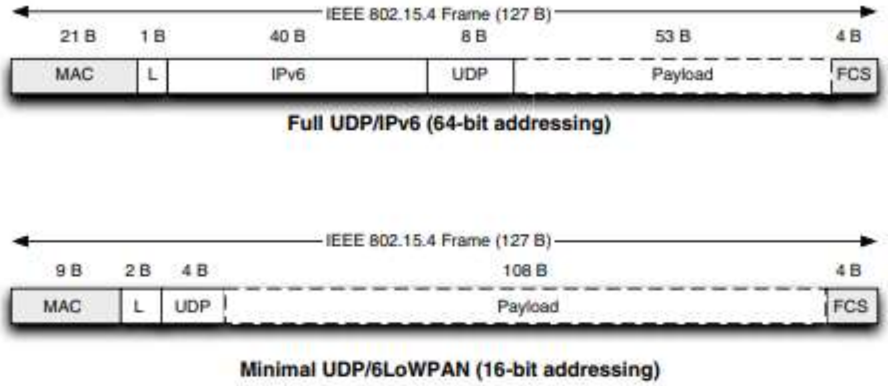

Fig: 3.4 6LoWPAN header compression example (L = LoWPAN header).

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Dispatch and LOWPAN_IPHC    |   LOWPAN_NHC  |  Src  |  Dst  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          UDP Checksum         | ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Fig:3.5 6LoWPAN/UDP compressed headers (6 bytes).

- The LoWPAN header consists of a dispatch value identifying the type of header, followed by an IPv6 header compression byte indicating which fields are compressed, and then any in-line IPv6 fields. If, for example, UDP or IPv6 extension headers follow IPv6, then these headers may also be compressed using what is called next-header compression [ID-6lowpan-hc].
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- An example of 6LoWPAN compression is given in Figure 3.4. In the upper packet a one-byte LoWPAN dispatch value is included to indicate full IPv6 over IEEE 802.15.4. Figure 3.5 gives an example of 6LoWPAN/UDP in its simplest form (equivalent to the lower packet in Figure 3.4), with a dispatch value and IPv6 header compression (LOWPAN_IPHC) as per [ID-6lowpan-hc] (2 bytes), all IPv6 fields compressed, then followed by a UDP next-header compression byte (LOWPAN_NHC)

with compressed source and destination port fields and the UDP checksum (4 bytes). Therefore in the likely best case the 6LoWPAN/UDP header is just 6 bytes in length.

Mesh topologies

Mesh topologies are common in applications of 6LoWPAN such as automatic meter reading and environmental monitoring. A mesh topology extends the coverage of the network, and reduces the cost of needed infrastructure. In order to achieve a mesh topology, multihop forwarding is required from one node to another. In 6LoWPAN this can be done in three different ways: link-layer mesh, LoWPAN mesh or IP routing. Link-layer mesh and LoWPAN mesh are referred to as Mesh-Under as the mesh forwarding is transparent to the Internet Protocol. IP routing is referred to as Route-Over

Internet integration

When connecting a LoWPAN to another IP network or to the Internet, there are several issues to be considered. 6LoWPAN enables IPv6 for simple embedded devices over low-power wireless networks by efficiently compressing headers and simplifying IPv6 requirements. Issues to be considered when integrating LoWPANs with other IP networks include:

1. **Maximum transmission unit**: In order to comply with the 1280 byte MTU size requirement of IPv6, 6LoWPAN performs fragmentation and reassembly. Applications designed for the Wireless Embedded Internet should however try to minimize packet sizes if possible. This is to avoid forcing a LoWPAN to fragment IPv6 packets, as this incurs a performance penalty
2. **Application protocols:** Application protocols on the Web today depend on payloads of HTML, XML or SOAP carried over HTTP and TCP. This results in payloads ranging in size from hundreds of bytes to several kilobytes. This is far too large for use with 6LoWPAN Nodes. End-to-end application protocols should make use of UDP and compact payload formats (preferably binary) Technologies which are capable of the transparent compression of web services into a format suitable for 6LoWPAN Nodes are especially interesting.
3. **Firewalls and NATs:** In real network deployments firewalls and network address translators (NATs) are a reality. When connecting 6LoWPAN through these there may be several problems that need to be dealt with, for example the blocking of compressed UDP ports and non-standard application protocols used for 6LoWPAN applications, along with the unavailability of static IP addresses.
4. **IPv4 interconnectivity:** 6LoWPAN natively supports only IPv6, however often it will be necessary for 6LoWPAN Nodes to interact with IPv4 nodes or across IPv4 networks. There are several ways to deal with IPv4 interconnectivity, including IPv6-in-IPv4 tunneling and address translation. These mechanisms are typically collocated on LoWPAN Edge Routers, on a local gateway router, or on a node configured for that purpose on the Internet.

5. **Security:** When connecting embedded devices to the public Internet, security should always be a major concern as embedded devices are limited in resources and are autonomous. This is very much so with 6LoWPAN as node and network limitations prevent the use of the full IPsec suite, transport layer ("socket") security or the use of sophisticated firewalls on each node. Although link-layer security inside a LoWPAN (employing the 128-bit AES encryption in IEEE 802.15.4) provides some protection, communication beyond LoWPAN Routers is still vulnerable. This increases the need for end-to-end security at the application layer.