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Seamless Integration of Distributed Internet Devices for Pervasive Architectures

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Abstract: Traditional but proprietary infrastructure networks for building control and facility automation, such as LON, EIB, etc., can lead to difficulties and costly gateway structures in approaches of integrating them into wider intranets and the internet. "SmartIP devices", i.e. small sub-computer nodes with fully integrated IP stack, have been developed and deployed. They provide not only a replacement, but additionally open a large range of new application areas. Small devices with actuators and sensors, for in/output, and local positioning systems, providing an IP socket connection and an optional HTTP server, are programmed in Java as "internet appliances". Self-configuration and ad hoc networking mechanisms allow user-friendly plug-and-play operation. Cabling cost is reduced by supplying electricity via "Power over Ethernet" (no power cable); or by connecting them wirelessly (no network cable). With the aim of Seamless Networking, "Gateway-less" or "Zero-gateway" structures become possible. The user benefits from ubiquitous networking support in daily routines, e.g. the transition between home - car - office.

1. Introduction

Integration of infrastructure networks for building-control ('infranets') into wider intranets and the internet has often been discussed recently within the context of bringing Mark Weiser's [1] idea of Ubiquitous Computing into reality.

Benefits are expected for remote facility management (teleservices), e.g. for organizations running office buildings and/or collecting resource consumption parameters from residential facilities; as well as for users, i.e. people working in offices and living in homes being able to check and control functions remotely, automate daily routines, and employ comfortable multimedia edge-devices for entertainment and home surveillance.

When the authors had the opportunity to transfer prototypical approaches from the research environment (at Fraunhofer FOKUS) into industrial practice of the representational headquarters of Deutsche Telekom AG, a number of lessons have been learned.

The infranet technology used within this building, besides IP[1] based systems, mostly consists of LON [10], EIB [11] and CAN [12] based control networks, proprietary sub-systems for specific tasks, and a LON based [9] active badge system [3] for location dependent services.

The integration of these infranet sub-systems, done by FOKUS spin-off company Ivistar AG [8], had to make them accessible from a variety of end-systems for different purposes. The task focused on user and operator-specific control.

It turned out that the hardware effort for the gateways between the proprietary infranets and the intra/internet was extremely high. It would have not been affordable for a normal office building. Practically, the IP gateways and interface servers in this case now form an additional backbone-skeleton to the underlying infranets, which scales exponentially with the latter (with reasons caused by the limited storage capacity of the proprietary infranet nodes).

1. IP: internet protocol

In other words, there is a mismatch between cost and added value. To solve this problem, we changed our strategy. We currently focus on leaner, more cost effective solutions, which involve "SmartIP devices", i.e. sub-computer nodes with fully integrated IP stack. With the aim of *Seamless Networking*, these nodes can be embedded in "Zero Gateway" or "Gateway-less" architectures.

The advantage of our platform as introduced in [8] is that this migration can be done transparently for applications and users, and proprietary legacy devices can still be supported within the transition period.

Within the next section, the hardware of the SmartIP devices is introduced. Section 3 provides an overview of the system architecture, followed in Section 4 by a brief discussion of a specific messaging protocol running on top of this platform. Section 5 points to the directions of future work.

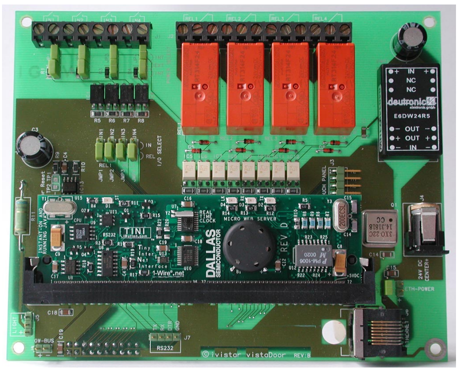
2. SmartIP™ Devices[2]

Our approach of *Seamless Networking* provides a suite of SmartIP devices which have been and are being developed at our institute in cooperation with its commercial spin-off company, Ivistar AG.

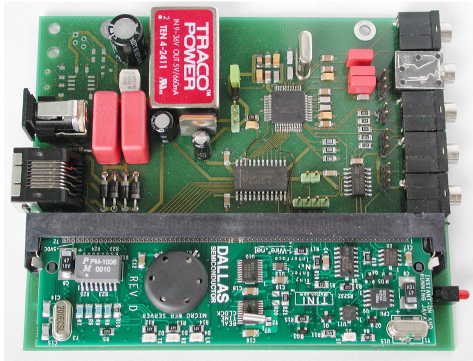
From the experience of integrating building-wide infrastructure networks, such as discussed in the introduction, into corporate intranets and the internet, the decision has been derived to focus current and future development on

2. SmartIP is a German trademark of the FOKUS spin-off company Ivistar AG.

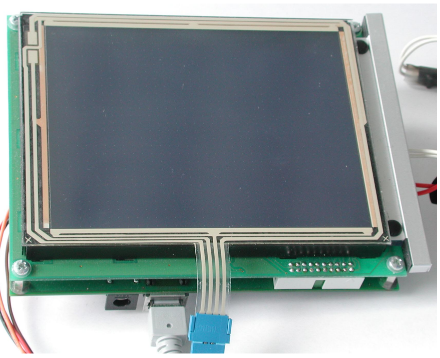
Tini board with JVM and IP communication



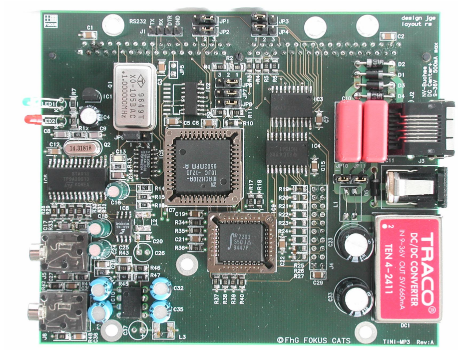
Relay and sensor board



Audio encoder board



Display, with optional touchscreen



Streaming audio MP3 player board (Tini board on back)

Figure 1 Tini board and a variety of SmartIP hardware.

manifold sensors and actuators on *fully IP compliant* nodes with Java, instead of providing expensive gateways.

To program all these nodes as small “internet appliances” in Java, like any other PC or work-station platform, is a great advantage.

Current work focuses on the implementation of a UPnP stack and “virtual” UPnP devices representing localisation badges (users). This results into a fully transparent location-aware system with minimal management requirements, which can be altered while running (Plug-and-Play). Applications and services will recognize and communicate directly with virtual badge devices (featuring an automatically updated location property).

2.1. Core device

All components discussed below currently incorporate a low cost micro controller module (Dallas Semiconductor / Maxim TINI, Figure 1, left) that offers a Real Time Operating System (RTOS) and a built-in Java Virtual Machine (JVM). It has the size and form-factor of a PC SIMM memory module. The services implemented on these boards can be accessed in different ways:

- via socket communications,
- via a built-in Web-Server,

While our current hardware is still a little too large to be integrated in standard light switches (which have standard cylindric wall mounts of 68 mm diameter in Germany), a single-chip controller solution with a fully implemented IP stack is under development as a further hardware miniaturization.

A large, new office building – which is presently being planned by Deutsche Telekom AG – will serve as an installation base for a significant number of such miniaturized IP devices, thereby allowing to produce a sufficiently large lot to be competitive in price compared to “traditional” building networks like LON and EIB.

2.2. Portfolio of task-oriented devices

Employing the TINI board discussed above as a core, the following SmartIP devices (partly shown in Figure 1) have already been developed. All these devices receive their low voltage power (24 or 48 V) through the TP cabling, i.e. using Power over Ethernet [5].

- Digital I/O card with 4 output channels with 230 V / 16 A power switches) and 4 sensor input channels.
  It can serve as the core for all controlling of light, heating, household appliances, etc.. The sensor inputs can be driven by motion detectors, temperature triggers, door contacts and others.

- Customizable D/A and A/D converters; for a large variety of converter chips with different precisions and sampling rates.
  These converters can be used for a variety of measuring and sensoring, such as temperature, wind speed, sunlight, etc.
- Dimming device, which consists of a low-end D/A converter controlling a power regulator (triac).
- Online Door-Plate,
  It uses a b/w 320 x 240 pixel LCD display with touch screen, and a power switch (for the door lock). The door-plate interworks with an internet based room booking and accounting system, which can provide a one-time PIN for accessing meeting rooms and shared offices.
- Graphical User Interface device.
  Similar to the door-plate, this device uses a b/w 320 x 240 pixel LCD display and a touch screen, providing smart buttons for interaction with the home/office environment.
- Active desktop image frame, using a 320 x 240 colour display.
  Processing the images for this desktop decoration currently reaches the limit of the TINI module. Larger active image frames, using 18...22” LCD displays and large plasma screens have also been developed, but use an embedded computer module with more processing power. This is appropriate as the larger displays also provide more room for the computer. The advantage of the all-IP system approach is the compatibility and transparency of usage.
- MP3 audio streaming player, including a 1 W power amplifier.
  The audio amplifier is powered over the network cable. This avoids separate audio cabling, e.g. for announcement speakers in waiting rooms. Another application scenario is an audio-follow-me environment, in combination with the local positioning system discussed below.
- MP3 hardware encoder for audio capturing / streaming. This device is the opposite of the MP3 player. It can be used for continuous audio surveillance or for entertainment in combination with an appropriate source, which may be an FM radio (below) or an internet radio stream. A specific application is the decentralized capturing and compression of voice messages (sent to playing devices described above) or commands, sent to a centralized voice recognition engine.
- FM radio, tunable and controllable via IP as an add-on for the MP3 encoder.
- Specific gateway solutions.
  In some cases, networks other than IP based are necessary and cannot be avoided. The CAN bus (Controller Area Network) is used in automotive environments and fulfils stringent real time requirements. Firewire (IEEE1394) meets the QoS parameters of high-end digital audio/video entertainment data. To exchange control information with such networks, cost-efficient gateways have been developed on the SmartIP platform.
- Local Positioning System, based on an improved active badge approach, is discussed separately in the following section.

2.3. VistaSeek Local Positioning System

The developed Local Positioning System (LPS) provides major improvements compared to the traditional badge/sensor pairs in Active Badge systems. The advantages described here are achieved by introducing a third major component type (Figure 2), counting now as:

1. Stationary, stand-alone infrared ID beacons,
2. Mobile, IR receiving and RF transmitting badges,
3. Stationary RF receivers with LAN (or WLAN) interface, realized as a SmartIP device.

2.3.1. IR ID beacon. The beacon devices are used as *not-networked* tags in large numbers at lots of places. They periodically emit location information (the location ID based on a “silicon serial number”) in programmable time cycles. The signal strength (and thereby the maximum transmission distance) can easily be adjusted. Power consumption is not an issue because of the fixed location. Standard remote control components can be used and result in a very inexpensive bill of materials. As the IR ID beacon transmitter is so simple to realise, the hardware is currently being added to all SmartIP devices introduced in Section 2.2, which can then be equipped with IR LEDs wherever they are deployed in the room.

2.3.2. IR receiving and RF transmitting Badges. The form-factor of the badge is determined to be easily and visibly worn as a corporate ID card. The badge, slightly thicker than a credit card, listens to IR location IDs in varying time cycles, depending on the motion of the badge (more often while moving). Because the IR ID beacon transmits with a relatively high power, the sensitivity of the IR receiver is not critical, and the receiver can be implemented with inexpensive remote control components as well. The low bit rate also allows indirect transmissions (reflections) out of sight of the beacon with a distance of up to 8 m.

When a new IR ID has been received, the badge transmits a telegram to a base station via RF, consisting of a unique badge ID and the received location ID. A low cost 868/915 MHz FM transmission module with 10 mW output power allows uni-directional transmission distances of up to 30 m in-house, up to 100 m outdoors.

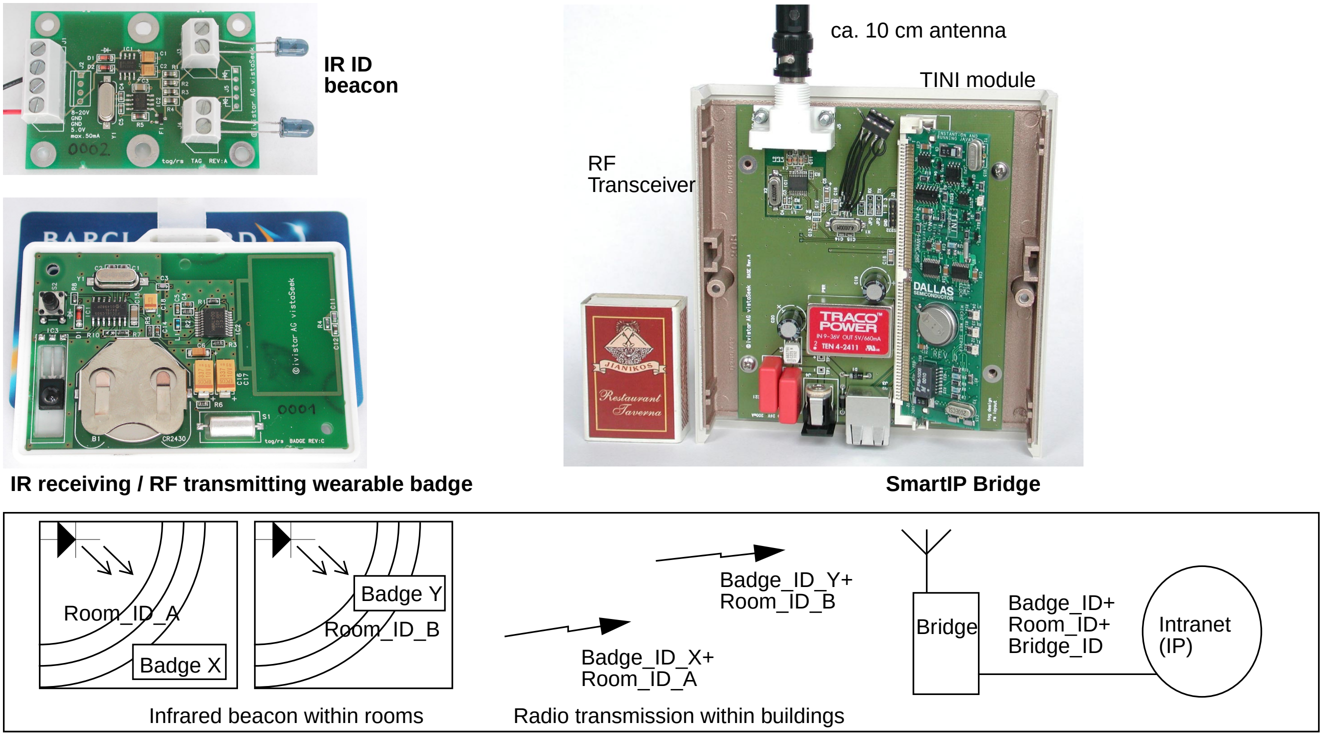


Figure 2 Local Positioning System: Hardware, System Architecture and Signal Transmission

2.3.3. SmartIP bridge. The RF base station, providing a cell within the building/campus connected to the IP network (wired or via WLAN), has been designed as simple as possible. For future applications, it already includes an RF transceiver, although only the receiver path is used currently. An internal bus allows cascading a couple of bridges, thereby saving further cabling costs for topology reasons.

2.3.4. LPS Architecture.

Figure 2 (top) illustrates the complete hardware setup. Compared to the Olivetti Active Badge [3] and the ELPAS system [9], installation costs could be drastically reduced. Instead of needing one expensive, networked IR sensor per room, only the cheap beacons are required. A group of 5..15 rooms share one of the more expensive and networked bridges.

Figure 2 (bottom) illustrates the system architecture and the signal transmission. The Room_ID beaconed by the cheap IR transmitter is received by the badge. The latter adds its own Badge_ID and transmits the information via RF to the bridge. The bridge either stores the location information for direct access, or pushes it towards a centralized server somewhere in the IP based intranet of the company, after adding its own Bridge_ID to the message.

Distributing bridges within a building and over a corporate campus leads to a cellular topology, where the radius of a cell is approx. 30 m indoors and 100 m outdoors.

A specific advantage of the system approach is the possibility to place multiple beacons in one room. Due to the burstiness of the IR signals collisions are rare; and the IR power can be adjusted. Thus, large rooms can be covered easily, and positioning within the room is possible, e.g. by placing a beacon (with reduced power) at each Point of Information in an exhibition.

Outdoors, sunlight disables reliable IR transmission. In this case, the badge is localized on cell level, and the approximate distance from the bridge can be determined with RSSI (Receiver Signal Strength Indication).

The same cell level localization happens when the badge is concealed indoors (e.g. put into a pocket), or for privacy reasons certain locations (e.g. bathrooms) do not feature a beacon. The user or the secured object does not disappear, but transmits its own badge ID to the cell's bridge, indicating at least the part of the building to look for it.

2.4. Wired vs. wireless?

A hot topic in the research of pervasive computing is the question whether our future will be wired or wireless. *Sensor* nodes might become as small and inexpensive, that they can be 'painted' to the walls, powering themselves [2] for a lifetime until the next refurbishing. However, nobody speaks about *actuator* nodes in such a wireless context. The reason is simple: actuators need substantially more energy for performing any perceivable action, e.g. playing

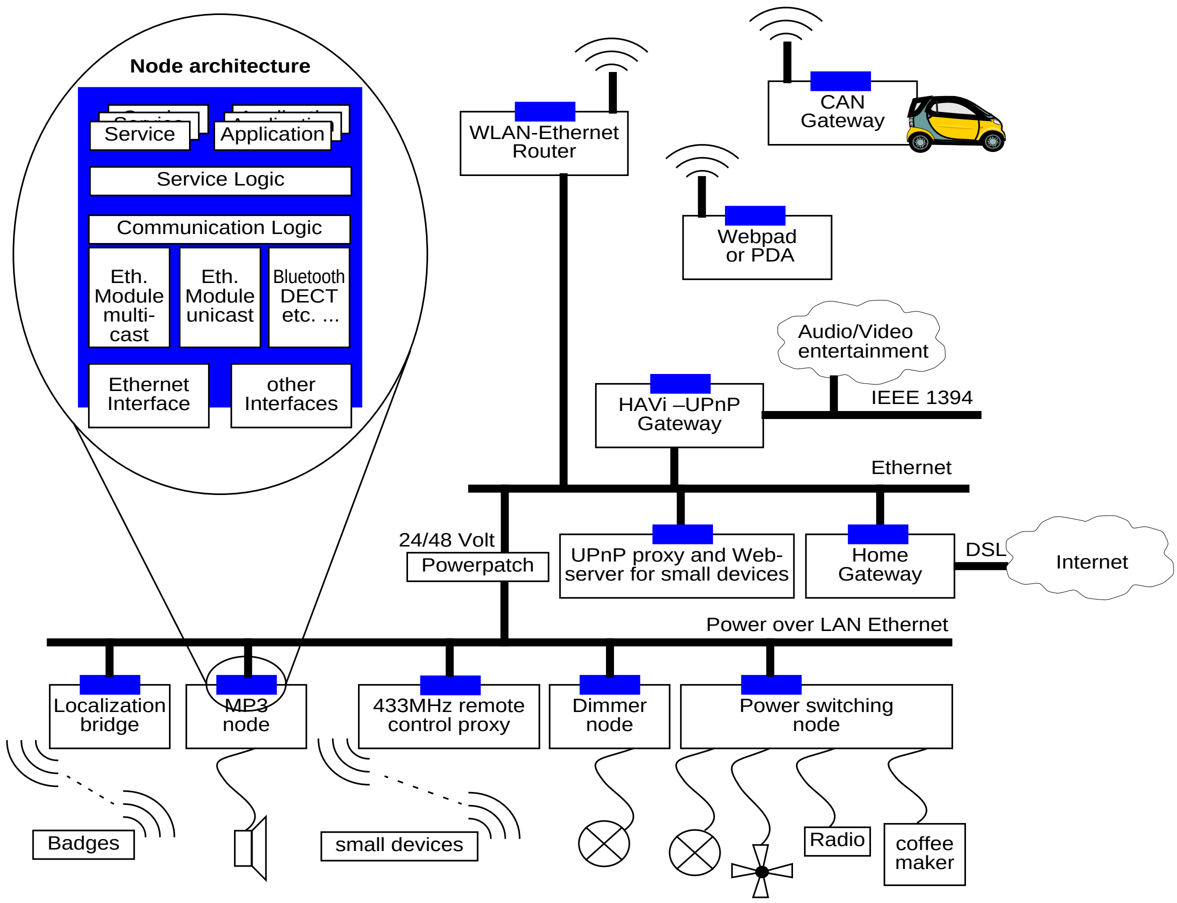


Figure 3 Overall system structure – (example: home environment).

music, switching or displaying something, than sensors need for measuring and communication. In consequence, either a replacable power supply is maintained in shorter intervals, or the appliance is wired.

Batteries in mobile devices carried around by a user are easy to maintain, because the user recognizes the exhaustion. This becomes different for pervasive devices in the background, in particular if there are many, and if reliability is considered. E.g., a battery powered temperature sensor could fail to signal the measured values, being not even able to signal its battery-low status, because a sudden drop in temperature causes a sharp decline in battery capacity.

The answer to the question “wired vs. wireless” obviously will be found by intelligently combining the benefits of both technologies. The SmartIP approach discussed in this paper does this in a transparent manner.

Cabling cost is reduced by supplying electricity via “Power over Ethernet” [5]. Cabling systems are unified, only TP CAT5 (or up) cabling is used, providing much more flexibility than proprietary cabling, e.g. for the audio speaker system. The wired technology is combined with wireless solutions wherever they are appropriate, as radio datagrams (e.g. in the positioning system), or WLAN (supporting IP) for distant places or mobile devices.

3. System Architecture and Application Examples

When discussing architectures built with the SmartIP devices, the great variety of possible applications has to be considered. Therefore, Figure 3 can only give an example (scaled to a home environment), and does not depict all devices that have been developed.

A zoom view of the general architecture of a node is provided left in Figure 3. Each of the TINI nodes can have one or more communication interfaces. The first one is typically used for Ethernet, while others can be used for further media, e.g. FireWire IEEE1394, Bluetooth, the radio data link in the localization bridge, etc.

The driver modules support the respective physical interface. In case of Ethernet, the unicast driver is used in normal communication, while the multicast driver is necessary for the service discovery process.

A communication logic unifies the logical access to the different drivers. On other hardware platforms (e.g. PCs for tasks requiring more resources than the TINI provides), the communication logic provides access to the system-provided communication interfaces.

The service logic allows an abstract handling of service objects, independent of the underlying node hardware and topology. Systems freshly plugged into the systems announce their services to the remaining community of devices and are recognised in an ad hoc structure. E.g., a dimmable lamp is recognised by appropriate user interface devices, and the respective icon is inserted into the GUI.

Continuing to review Figure 3 from the bottom, the devices which receive their power over TP cabling can be recognised. The ‘powerpatch’ only feeds 24 or 48 V into the cables, and is completely transparent regarding the Ethernet, the cables can even be connected to the same hub/switch than non-powered devices.

Functionalities like the internet home gateway (also firewalling for home security), UPnP proxy, webserver, etc. can share the same full-size PC, or distributed in larger scenarios.

The gateway to the audio/video world, supported by the FireWire IEEE1394 bus, also provides translation between UPnP and HAVi (Home Audio Video Interoperability) [6], a standard becoming increasingly recognised by AV manufacturers.

A router for wireless communication provides communication with mobile devices, etc. Webpads or PDAs providing GUIs, or the car in the garage, where car-internal parameters can be accessed via the CAN gateway.

A number of application areas can already be demonstrated with the available use-cases of location-aware and person-aware reactions of appliances.

A WLAN hand-held device (e.g. a PDA) can be used to control functions in the setup, e.g. switching or dimming lamps, or call back stored scenarios.

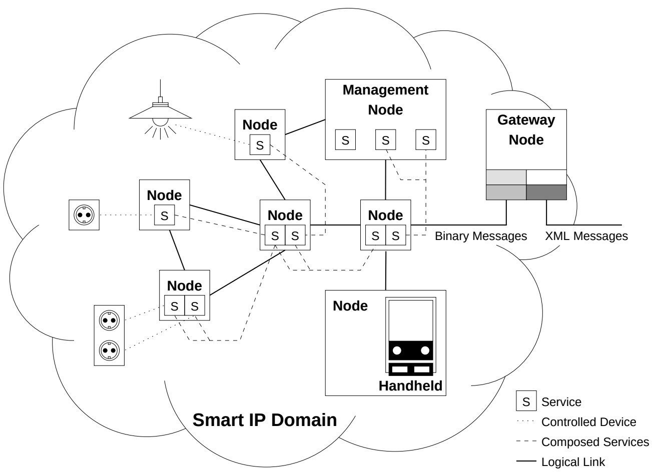


Figure 4 I-net messaging domain

An audio follow-me function considers the preferences of the user, and additionally moves the audio stream from one streaming MP3 device to another when the user changes position.

The same functions can also be accessed with the stationary Online Door-Plate or GUI device, providing a touch-panel.

Translated into HAVi, all home control and surveillance functionality can be accessed from the home TV.

4. Individual Centric Networking (I-net) messaging protocol

With the focus on the integration of ambience awareness and personalization issues into a joint effort for the provision of “user centric” or “I-centric”, the I-net project[1] has developed a messaging protocol primarily targeted to embedded devices in body and personal area networks. It has been applied to the architecture of SmartIP devices discussed in the previous sections.

In I-net, sensors and actuators together with small computing devices organize themselves in an ad hoc network. This network then provides a service view dependent on the user's current perspective.

A network node in I-net can be connected through a variety of communication protocols. The most common case is the usage of IP (internet protocol). However, other network protocols can be supported for the inter-node communication also. There are no topological restrictions from the perspective of I-net messaging, in particular, nodes can be chained.

Among such nodes are nodes which are able to communicate with one or more physical devices on one hand and a terminal on the other (Figure 4). A physical device provides functionality (e.g. a light switch, a lamp). A terminal reflects the variety of possible user interfaces being able to communicate with the nodes (e.g. a PDA, a PC). Nodes can provide one or more services.

The I-net messaging protocol provides basic communication for devices or services to announce their presence, and to invoke services it provides. The protocol has been designed in particular to support small, very resource limited IP devices, such as the TINI board introduced in Section 2.1.

A proprietary, lightweight message format has been defined. All I-net compatible components, providing at least one service, must provide the information about:

- the devices and services currently available in the network,

1. I-net is a joint research project of the two Fraunhofer institutes FOKUS and IZM (Institute for Reliability and Microintegration).

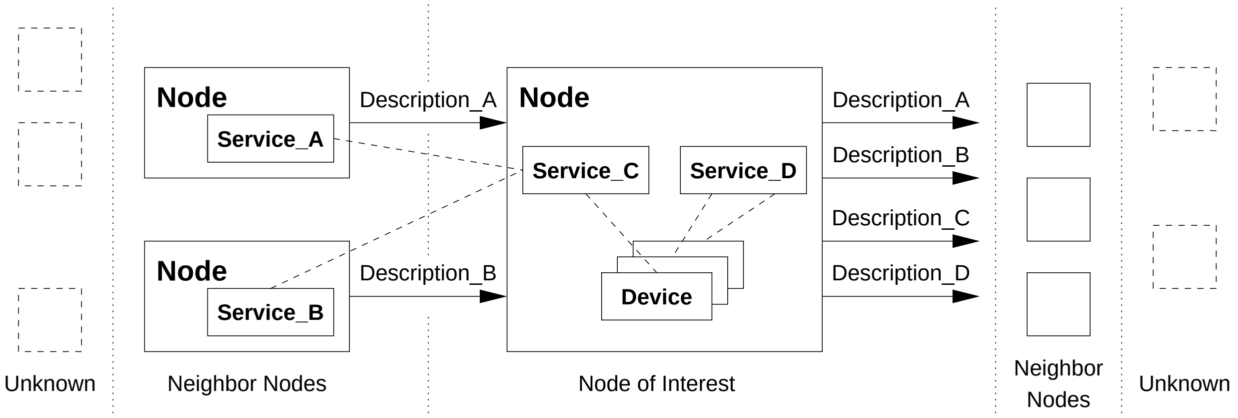


Figure 5 I-net messaging: neighbor relations

- capabilities of each device, or services they provide, and
- properties of the device including the type of each property and their current values.

A predefined message structure allows the communication between the components, device discovery, device monitoring, and device configuration with limited computing power. Therefore, the messages are defined in a compact, binary format.

While parsing XML would be too resource demanding for the small computing nodes, mapping rules have been defined for the transformation into a XML description of a service. This allows gateways with sufficient processing power to connect the I-net world with other domains, e.g. UPnP or HAVi.

I-net does not require a central instance, it operates on peer-to-peer communication. A propagation mechnism ensures that any node within a domain can learn about all service descriptions, even when it is topologically hidden somewhere in a chain (Figure 5). Device discovery and device monitoring are implemented.

The architecture also provides a simple way of invoking a service provided by any component in its network domain. As the available services are self describing, it is easy to identify how to invoke any service.

In devices desinged to present user interfaces, the services can be represented appropriately and dynamically. E.g., their status can be displayed and control buttons can be activated in a GUI.

5. Outlook

Further work will be invested into the enhancement of the UPnP stack, providing “virtual” UPnP devices dependent on their detected location.

The further miniaturized hardware – matchbox-sized MicroIP devices, as mentioned in Section 2.1 – is currently being tested within the SmartIP environment for compiance with I-net messages.

The OMG software architecture of SDOs (Super Distributed Objects) [7] is being implemented by a complementary group of researchers on top of our hardware platform.

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