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FRAUNHOFER INSTITUTE FOR INTEGRATED CIRCUITS IIS

s-net®
WIRELESS SENSOR NETWORKS

s-net®
FROM SMART METER TO SMART OBJECT

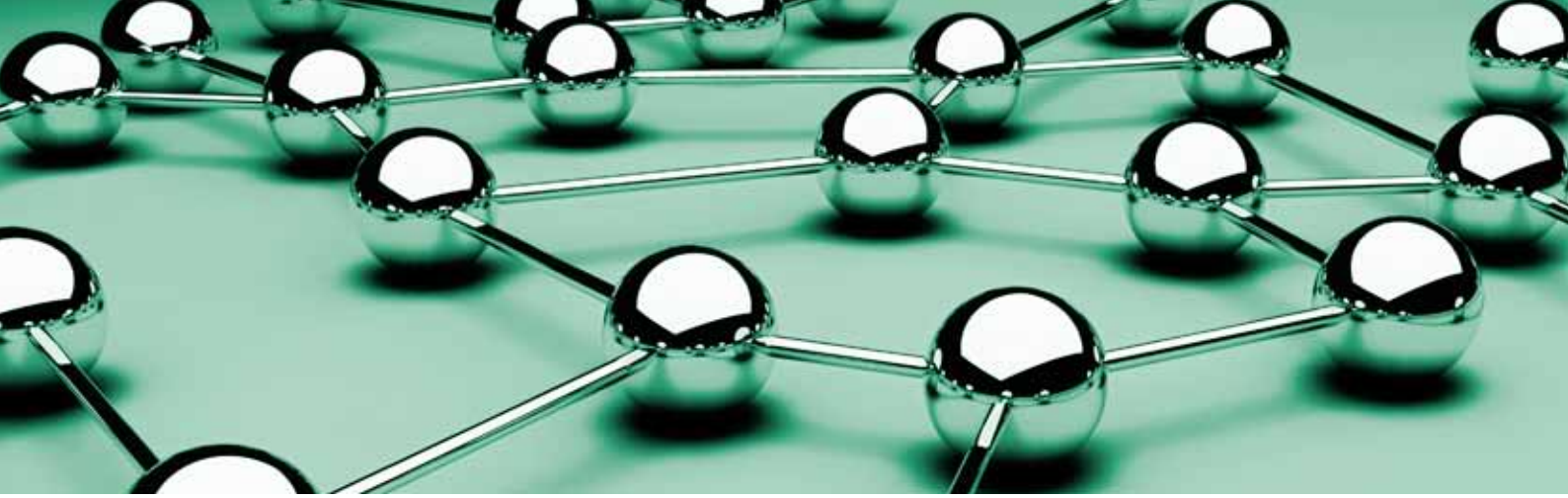
With the increasing requirement for information, security and flexibility, wireless sensor networks are used nowadays in many areas of daily life. A sensor network is made up of spatially distributed sensor nodes, which interact with one another independently and, depending on the application, with the existing infrastructure by radio. This serves the purpose of acquiring, processing, forwarding and providing digitalized information from the physical environment. Sensor networks may vary in terms of the type of networking, topology and direction of data flow. As there is a large number of identical sensor nodes, there ensues a scalable redundancy and inherent fault tolerance.

Thus, thanks to distributed data acquisition, decentralized application software and intermeshed communication, wireless sensor networks open up completely new possibilities. Many applications from the industry and home sector could already be expanded thanks to wireless sensor nodes and have thus become more comfortable and efficient. There are examples of this in the energy sector (smart metering), in logistics (asset tracking) and in process optimization (smart objects). Unlike conventional technologies, such as RFID for example, wireless sensor networks can communicate actively and bidirectionally and do not need to be activated by a reader. For many years, the Fraunhofer Institute for Integrated Circuits IIS has been carrying out the research and application development required. Their activities stretch from radio nodes for simple point-to-point data transfer to small, centrally controlled networks to the large-scale, self-organized communication network.

With the s-net® technology, Fraunhofer IIS has been providing optimized communication protocols for the creation of extremely energy-saving wireless sensor networks since 2007. With the s-net ® technology, Fraunhofer IIS is focusing on three areas of application:

– Long-lasting systems for large-scale, distributed data acquisition or data collection
– Localization of persons and objects
– Smart objects for the autonomous processing of tasks

With its protocol properties, which can be flexibly adjusted, and an exceptionally low power consumption, which means a long operating time, the s-net® technology provides outstanding properties for solutions which are tailored to the customer's needs. The dynamic self-organization for low configuration outlay, low maintenance and robustness also contribute to the successful implementation of sensor network based solutions on the basis of s-net®.



EXTREMELY ENERGY-SAVING WIRELESS SENSOR NETWORKS – A TECHNICAL CHALLENGE

Each application has differing requirements. In the case of communication standards, these are only partially taken into consideration because of the objective of broad application. Only optimized communication protocols can therefore provide a suitable solution. With the s-net® technology we provide our customers with the possibility of having an optimized solution.

One sensor network – many requirements

Each application has its own requirements with regard to quality of service of communication, energy consumption and system lifespan. And this is where the communication protocol plays a decisive role. Therefore, in terms of the design of a communication protocol, the following fundamental aspects must be clarified:

- Energy: How long does the system have to be operational with a battery?
- Latency: How long should it take for data to be processed or delivered?
- Scalability: How many participants should be able to communicate with one another and what is the spatial distribution? Are there mobile nodes or sub-networks?
- Data throughput: What is the desired volume of data traffic to be transferred over the network per time unit?
- Topology: Which node communicates with whom? Is the distribution of the nodes statically or dynamically variable?

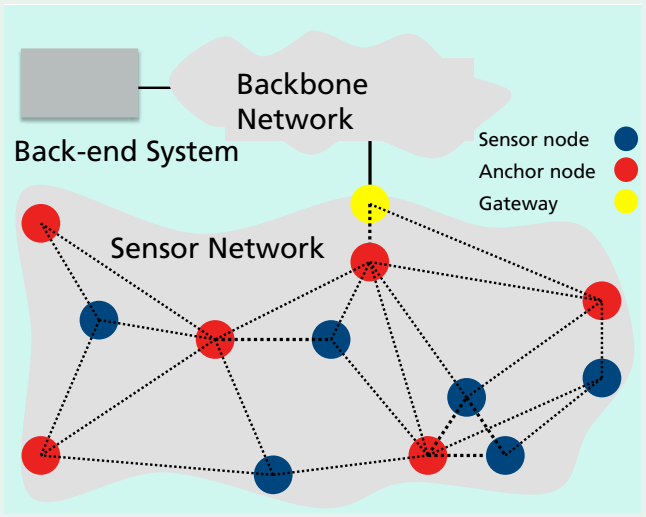
The energy consumption of a radio network is predominantly caused by transmission and reception. Additional, unnecessary energy consumption results, to give an example, from the collision of messages sent at the same time or from the reception of irrelevant messages. Therefore, for optimized energy efficiency, transmission and reception processes must be coordinated in order to achieve the shortest activity cycles possible.

One sensor node – many tasks

The sensor nodes in a sensor network interact with one another by means of wireless communication. In doing so, they take on various roles:

- Gateway nodes are responsible for the connection of the sensor network with a back-end system, e.g. an IP network
- Intermediate nodes are responsible for forwarding the data to the destination for providing information as a stationary basis (so-called anchor nodes), e.g. for localization
- End nodes are responsible for sensory acquisition, data processing or application logic

Communication takes place on three logical levels. On the application level, the application components on the nodes communicate with the corresponding components in the back-end system. On the so-called middleware level, fundamental services or complex processes between nodes provide the application components with their functionalities. If required, the middleware components communicate directly with one another. The transfer of messages via the sensor network is controlled by the communication protocol.



Reference model of a wireless sensor network

S-NET® PROTOCOL KIT

With s-net®, Fraunhofer IIS is making an effective technology available for the creation of application-specific sensor network solutions. The s-net® protocol technology has a modular architecture and enables an energy-saving and secure multi-hop data communication in wireless sensor networks. The proprietary media access protocol SlottedMAC is key and combines the efficiency advantages of a time division multiple access system (TDMA) with the scalability and flexibility of contention based protocols. Thus, a self-sufficient, battery-based operation of wireless sensor networks with low latency (delay time) is guaranteed.

Significant Characteristics

- Extremely low energy consumption thanks to time synchronization of the network and time division multiple access communication. Hence a long operating time is achieved for battery operated systems.
- Dynamic formation and self-organization of the network topology for low configuration outlay, low maintenance and a high level of robustness. The nodes synchronize and organize themselves along a tree structure.
- Multi-hop communication for data transmission via intermediate nodes. The scalable range of the multi-hop data communication ensures fast data transmission through the network.
- Flexible parameterization of the protocol properties for various application areas. Through this, the protocol can be adapted for various node densities, networking depths and data throughputs.
- Scalable frame length from 1 sec to 4 min for a flexible adjustment of energy consumption or latency to the application requirements.

The s-net® protocol technology enables the intermeshed networking of sensor nodes and forms the basis for the localization of nodes within the network. The quality of the networking is constantly monitored and the networking topology is dynamically adjusted if required. Because of the distribution of the sensor data and the limitedness of the sensor node resources, the overall functionality of a sensor network is only developed thanks to the cooperation and the combination of the individual sensor nodes.

Flexible platform for individual customer applications

With regard to the various requirements of the different applications, a system environment and a service-oriented architecture for sensor networks was developed with s-net®, which can be run on radio nodes which are particularly limited in resources. In doing so, the sub-functionalities of a node are realized in the form of functional components or services which can be found and used by other components. This software architecture presents a flexible platform for the creation of individual customer applications.

Intermeshed and secure data communication

The data communication in an s-net®-based sensor network takes place bidirectionally between the nodes. Mostly, the same communication paths are used, as they arise from the synchronization, that is a tree structure. Furthermore, it is possible to exchange data between all nodes in the radio range of a node. Thus data can be sent to a single node, but also to a whole group of neighboring nodes. For the secure data transfer of important data packets, a security mechanism is available. This mechanism signals the successful reception to a sending node. If this signal is not transmitted the packet is sent again. This process is repeated until a configurable threshold.

s-net® service manager for fast communication between applications

The s-net® service manager is the central component of the middleware which combines the higher services and applications with the subordinate protocol stack. All applications and services are identified and reached via their specific service number. The s-net® service manager processes all messages which have been received either wirelessly or by wire via the protocol stack and forwards these to the applications registered for them. Thanks to a dynamic registration mechanism, a 1:n communication can take place between several applications. This way, a message which was generated on a sensor node can be transmitted to various services on one or several other sensor nodes, without informing unaffected applications unnecessarily.

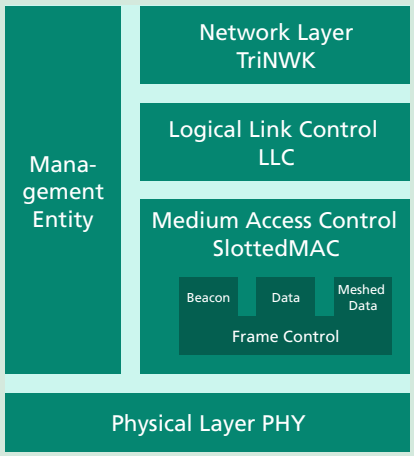
s-net® network gateway for integration into company networks

The s-net® network gateway (WSN gateway) connects wireless sensor networks with TCP/IP networks and thus serves for simple integration in existing network infrastructures. The WSN gateway makes the following services, amongst others, available:

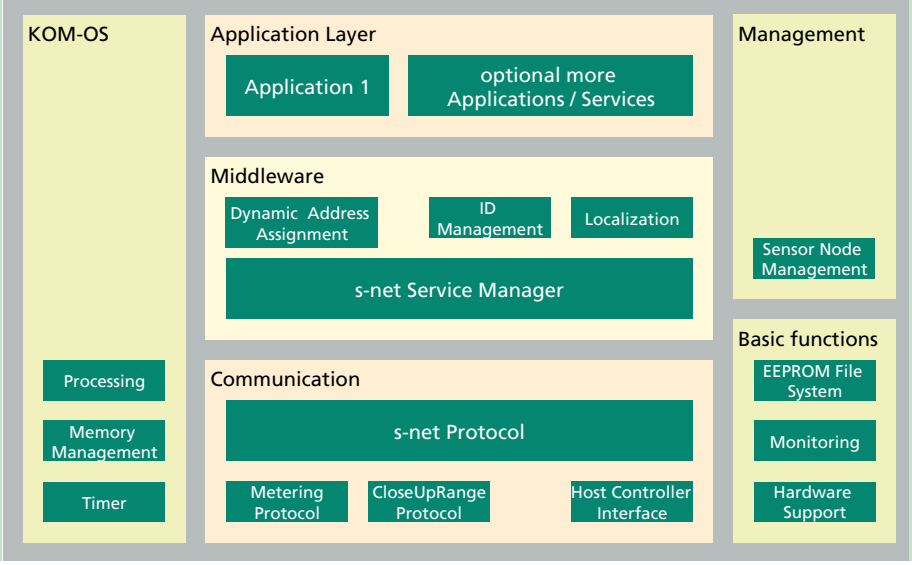
– DCAA (dynamic centralized address assignment): The DCAA is a protocol for the assignment of short sensor network addresses to a long, globally unique, identification number. This service enables an unambiguous assignment of messages to the respective sensor nodes and an efficient communication through short addresses
– Service subscription: The service subscription enables messages to be subscribed to based on the publish/subscribe design pattern. Network users, who are interested in the messages from a particular service can register on the WSN gateway and will then receive messages from the sensor network.

Inherent localization for location-based task processing

The intermeshed networking creates the basis for accurate localization of sensor nodes within the s-net® network. Based on an enhanced WCL algorithm (weighted centroid localization), the sensor node independently calculates its own position from the positions of all received nodes. As a result, the position is calculated in such a way that resources are spared and this can be signaled to a central entity upon request or at set time periods. As the position is calculated directly on the node, applications can also trigger an alarm without network communication, e.g. in the case of theft.



s-net® protocol stack



s-net® software architecure

S-NET® SYSTEM ENVIRONMENT

The s-net® system environment on the sensor nodes is made up of the s-net® operating system KOM-OS, monitoring mechanisms hardware drivers, the s-net® communication protocol, the application and a middleware. The sensor nodes have a host controller interface (HCI) for connection to the outside world.

s-net® operating system KOM-OS – a flexible construction kit for users and developers

KOM-OS is a multi-tasking operating system, dimensioned for an efficient use of the internal memory in embedded systems and wireless sensor networks. Thanks to its modular configuration, various applications and services, which run on the integrated systems, can be easily integrated into the system. KOM-OS presents itself to the users and developers as a flexible construction kit.

KOM-OS is a lean real-time operating system which was designed based on the principles of object-orientation and concept-based programming for embedded systems. It works with an preemptive multithreading process. This process makes it possible for individual applications to be developed on the sensor nodes without disrupting the chronological process of the communication protocol. In addition, KOM-OS also provides the opportunity of carrying out cooperative processing. The classic mechanisms of an operating system such as messaging, memory management, system time, timer and object management are available.

Easy application integration

Project-specific applications can be integrated into the s-net® system environment via three different interfaces:

– The application can be derived from a system template which is then saved within the system. The KOM-OS operating system provides all required functions in order to define and integrate an application component.
– For data communication with other sensor nodes, services or the back-end system, an application can use the service-oriented messaging exchange system of the s-net® service manager.
– For local hardware drivers and comparable applications, special interfaces are used for programming the basic function or control components.

S-NET® HARDWARE REFERENCE DESIGN

The individual nodes in a sensor network typically consist of a radio front-end and a microprocessor system, on which a protocol stack and the applications run. In a sensor network, the affected nodes take on various roles. Stationary nodes mostly serve the purpose of transferring the data (router) or form the stationary basis for the localization (anchor nodes). The mobile sensor nodes which, depending on the application requirements, are equipped with different sensors or actors, carry out the tasks allocated to the sensor network (e.g. collection of temperature data). The transition from a sensor network to a further processing network, e.g. an IP network, is done by a gateway node.

The sensor node hardware platforms developed by Fraunhofer IIS work in the, amongst others, 868 Megahertz and in the 2.4 Gigahertz frequency range, with minimal energy consumption and high data rates. The reference designs have various application focuses, which range from smart metering to sensor data collection and status monitoring to localization. They form the basis for customized system and product developments. System properties, sensor technology, interfaces and design can be individually adjusted. They enable both simple telemetry applications as well as complex wireless sensor networks.

Energy efficient design

For all sensor network platforms from the Fraunhofer IIS, the lowest possible energy consumption was aimed for during the design process in order to be able to achieve extremely long-life battery operated systems. For self-contained battery systems, we draw on key technologies from the power management and energy harvesting sectors.

Platform abstraction for a quick adaptation to customer requirements

In order to be able to react as quickly as possible to individual customer requirements in terms of hardware properties, Fraunhofer IIS created a platform abstraction. With this, an appropriate firmware can be generated in a short period of time depending of the modules and components used.

Transfer into series production

We have many years of experience in the system integration, transfer into series production and conformity testing and approval of wireless sensor networks. We support our customers from the design stage to the finished product: Consistent design flow, specification, product and circuit design, circuit diagram and PCB design, production preparation, pre-compliance tests, conformity evaluation and market access (e.g. legal conditions).

APPLICATIONS AND PROJECTS

Numerous applications can be expanded thanks to wireless sensor nodes and thus become more comfortable and more efficient. With the s-net ® technology, the Fraunhofer IIS is focusing on three areas:

– Long-life systems for distributed data acquisition (e.g. smart metering in the building sector)
– Localization of persons and objects (e.g. asset management in clinics)
– Systems for the independent processing of tasks (e.g. smart objects for the monitoring of supply chains)

Over the last few years a multitude of measurement, monitoring and control applications have been created with wireless sensor networks based on the s-net®-technology.

Project examples

Smart metering – wireless recording of consumption

Consumption-dependent tariffs, automated meter reading and exact forecasts are possible with the use of wireless sensor networks in smart metering. Up until now, when the household meters were being read, each individual meter had to be checked directly, however with the s-net® technology it is possible to read all meter readings by radio. The radio nodes used, exchange bidirectional data wirelessly with a master node, which then collects this data and sends it on to the selected request station. This greatly minimizes errors and outlay, which exist when the meters are read manually. Fraunhofer IIS provides all the important components for the smart metering sector: From licensable hardware design for the radio modules in the meters to the individually adjustable protocol software for the networking of the individual radio nodes to the modular service and application modules. The s-net® technology is adjusted to meters and meter protocols via flexible interfaces. On the basis of the patented media access protocol SlottedMAC from Fraunhofer IIS, the company VERAUT GmbH, for example, was able to realize their product range VERICOM for the wireless transfer of consumption data. The innovative technology permits a bidirectional multi-hop communication. This way, for example, instructions or commands can be sent to the meters via several radio nodes. The extremely low power consumption provides for a long lifespan of the battery operated systems, up to twelve years.

Smart objects – Information extraction for the Internet of things

The Fraunhofer IIS s-net® technology for extremely energy-saving, wireless sensor networks acts as a basis for so-called smart objects in various applications. For this, objects are equipped with mobile sensor nodes and thus become "smart objects". In real scenarios, these smart objects carry out varied roles. In order to distribute these application tasks modularly as software components to the s-net® nodes, the service-oriented communication platform was used.

Thus various application and middleware services can use the s-net® technology as a multi-functional platform at the same time and independently of one another. The lead project Aletheia supported by the German Federal Ministry of Education and Research serves the purpose of obtaining, for example, an integral view of product-related knowledge for manufacturers, retailers and customers. In this project Fraunhofer IIS deals with the use and integration of wireless sensor networks for information extraction from the physical environment. In an application scenario, information on integrity violations concerning products, pallets and containers are identified, localized and communicated with the help of smart objects. Damages occurring to the product during transport or the unauthorized opening of containers, for example, are considered as integrity violations. In a further application scenario, sensor networks are used for the monitoring of machines or plants and can thus support the work of maintenance personnel. In

both application cases, the wireless sensor networks are connected to semantic information systems via a service-oriented architecture.

The EU supported project SMMART (System for Mobile Maintenance and Trace in Aeronautics) promoted the use of sensor networks for the optimization of maintenance and replacement parts logistics for commercial vehicles. With the help of an example it could be shown that wireless sensor networks can help to monitor critical components on vehicles and send sensor data via a gateway to a central unit promptly. In 2009, the advanced EU research project MoDe (Maintenance on Demand) began. This project looks at the use of wireless sensor networks in the field of requirement-oriented maintenance of commercial vehicles. The objective is a sensor-based optimization of maintenance phases, repair cases and downtime of commercial vehicles.

Localization of persons and objects – Asset tracking and process management in clinics and hospitals

With the OPAL Health project supported by the German Federal Ministry of Economics and Technology, processes in the day-to-day business of the clinic are optimized and made more secure. The most important innovation of the project was the development of a multi-functional platform of mobile, intelligent, wirelessly networked objects and the integration of these into the hospital information systems.
They serve the purpose of the localization and temperature monitoring of blood reserves, of the assignment of the blood reserves to the patients and of the localization of medical equipment. The services carried out in the OPAL Health project are:

– Asset tracking: Smart objects convey the current position, either periodically or on request. Furthermore, with a command, every node can be addressed, in order to issue an acoustic signal when searching for a certain device.
– Condition monitoring: This service transmits the temperature of blood products at an interval which can be configured. Each temperature value is also persistently saved on the node so that it can be sent later, if required.

Furthermore, in the project Olog-PAT (supported by the Bavarian government with EU EFRE funds) a sensor network based system for the improvement of patient logistics in clinics was created. The localization of patients takes place using the s-net® technology of the Fraunhofer IIS for wireless sensor networks. With this, precise process information for the affected departments can be generated. This means reduced outlay for coordination between the hospital departments, improved documentation and increased transparency with regard to the load statuses of resources. Furthermore, long search processes are avoided. A generic platform was created for the hospital environment, which satisfies usual requirements of the health service:
– Identification of objects and persons
– Monitoring and documentation of status and environmental parameters
– Localization of persons and objects
– Recognition, documentation and thus the monitoring of important events

Security
With regard to applications in the area of safety and security, we develop robust systems which can be used for the large-scale monitoring in ad-hoc scenarios.

OUR OFFER

THE OPTIMAL SOLUTION FOR EACH APPLICATION

Thanks to distributed data acquisition, decentralized application software, self-organization of communication and multi-hop data transfer, sensor networks open up completely new possibilities. As sensor nodes normally have a limited amount of energy available (e.g. via a battery or energy harvesting), the realization of wireless communication presents a particular challenge. If additionally large networks, mobile users and active services are required, standard solutions, such as Bluetooth® or Zigbee™ for example, fail. An optimized communication protocol must then be used, for which, depending on the application, the requirements regarding the available energy, permissible latency, required data rate, number of nodes and desired topology must be clarified and weighed up. The weighing up is required as not all requirements can be satisfied to the same extent. In this respect, the special know-how of Fraunhofer IIS is used in the development of an individual customer solution. In each new project we run through the steps stated below with our customers in a requirement and design phase.
In doing so we guarantee you exactly the solution you require.

Once the requirements and their priorities have been determined, we draft the solution idea with you and work on a solution design:

- Determination of protocol parameters
- Analysis of data quantity, data back-up, aggregation / filtering
- Energy concept / estimates
- Integration concept
- Interworking with other radio systems
- Control concept
- ID and address concept
- Software architecture
- Concepts for update / maintenance / monitoring of the modules in operation
- Definition of the hardware platforms
- Interfaces / drivers
- Radio measurements in the target environment
- Estimation of the outlay for realization of the project, with time scale
- Allocation of responsibilities

The competences of Fraunhofer IIS in the area of wireless sensor networks reach from consultancy beforehand and the selection of the appropriate protocols to the development of individual customer solutions and applications.

Consultancy
Different applications with specific properties require a weighing-up of priorities such as energy consumption versus latency of data transfer or the selection of the frequency band with regard to security, fault and data rate points of view. In the design of a self-organized sensor network the determination of the requirements, which the application imposes, is therefore very important. The engineers at Fraunhofer IIS support you here with their knowledge and experience.

Licensing of the s-net® protocol development kit
In order to do justice to the various applications, the communication software must be able to be adjusted flexibly to meet the various requirements. Our s-net® protocol technology is designed for this thanks to its modular software architecture. Alongside standard solutions, primarily individual customer software packages are compiled. For an individual protocol compilation and/or expansion, we run through several steps with you:

- Clarification of the exact requirements for the system functionality with the customer
- Creation of a system concept with approval from the client
- Implementation of the system functionality
- Extensive system tests
- Documentation of the methods
- Support for the commissioning
- Release management
- Transition workshops and training courses

Licensing of hardware reference design
All hardware designed by Fraunhofer IIS for wireless sensor networks can be licensed for the customer's own product development. Fraunhofer IIS has finished partial solutions for radio modules in different frequency bands (402MHZ, 434MHz, 868 / 915MHz, 1.9GHz, 2.4GHz and 5.8GHz). The modules can either be produced unchanged, or the design documents can be the starting point for your individual solution.

As an independent development company for antennas, we also offer you a customized antenna design for your radio solution: Development, simulation, construction and test of various types of antennas can be carried out by us.

Development
With our s-net® protocol development kit and hardware reference design for the realization of large-scale and long life wireless sensor networks, we provide you with the basis for solutions which can be customized according to your wishes. As Fraunhofer IIS has finished part-technologies, we can provide you with a quick prototype development.

Supplementary technology offer
If batteries are not sufficient, or if you would simply prefer not to use these, the extremely energy-saving s-net® technology can also draw the required energy by means of energy harvesting solutions from the environment, e.g. from differences in temperature or vibrations. Fraunhofer IIS supplies individual components for this, such as finished or adjustable comprehensive systems for the system or device integration. For special fields of application, sensor nodes with our patented wake-up receiver technology are available.

FOR MORE INFORMATION, PLEASE VISIT

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