General Purpose Self-Managed and Eco-Friendly Wireless Communication Network for Forest Environment

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Abstract

Our goal is to create an eco-friendly network for the collection of data from the environment. The network must be energy-independent with the use of renewable energy sources. As a backup power source in the event of unfavourable weather conditions supercapacitors and other environmental friendly energy storage technologies can be used. Our proposed data network needs to be energy efficient and be able to manage itself without any external supervision.

Keywords: communication network, energy harvesting, environment monitoring, eco-friendly technology, energy accumulation, fuel cells.

1 Introduction

Quickly changing climatic conditions and the rapid emergence of modern information and communication technologies provide us with an opportunity to closely monitor the environment around us. By analysing these data we can better understand the environment in which we live, protect it and predict catastrophic events (fires, floods, storms, landslides) or monitor the wildlife.

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In this paper, we provide a proposal of self-managed low-power wireless communication network which can be used to transfer different kinds of digital information obtained from various types of sensors and devices in the forest environment. Our goal is that the proposed network is environmentally friendly. We want to achieve this challenge by the exclusion of typical batteries, which contain heavy metals dangerous to the environment. Instead of batteries alternative energy sources can be used and they must be combined in such a way that the unfavourable weather conditions would not cause power failure. This also leads to the need for ecological energy storage, minimization of energy losses and making network operations more efficient as a whole.

2 Network Structure Specification

The communication network itself is one of the most important portions of the system. The main requirements for the communication network are: the use of low-power communication devices, the independence on the central communication network element, energy-efficient data transfer and the ability of the network to function in harsh environment.

Because the network is needed to be operational in the event of failure of several communication modules, it is necessary to design it with respect to the possibility of using alternative communication routes to prevent communication failures (Figure 1 – alternative routes are displayed in different types of lines). Such request complies with the use of unlimited topology also known as "mesh topology". This topology requires a communication module, not only to be able to process their own data, but also the ability to forward data of other elements.

Another important feature of the network is its self-organization. The network must be able to adaptively respond to the change of its internal structure. In case of adding or removing (due to failure) a communication module from the network, it must respond immediately and create alternative communication routes to maintain the communication in the network.

The proposed network shall not depend on a central network element, but at the same time it must allow the co-existence of elements with different configurations (different sensors, transmitters, power sources, etc.). It also needs to use special algorithms for self-organization and self-manageability, which eliminates the need for service interventions in the field and contributes to the long life of the network without any external supervision.

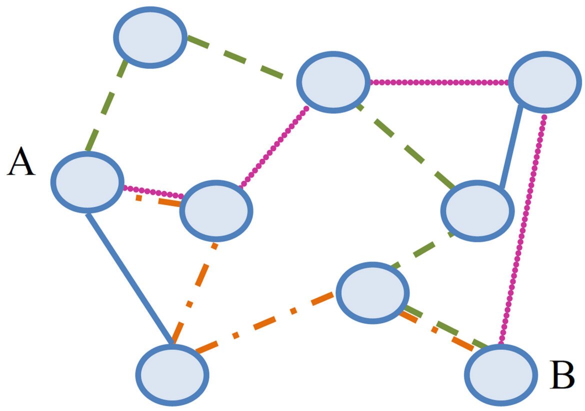

Figure 1 Example of mesh topology with alternate routes from point A to point B.

When creating such algorithms it is necessary to take into account the energy requirements of the network communication especially in case of using energy harvesting systems to collect the energy from the surrounding environment. We have therefore decided to optimize the network in the terms of energy consumption. This ensures an even distribution of energy consumption across the network, where all communication elements will be evenly loaded. Another way to reduce energy consumption of the network is the use of effective compression of transmitted data and compressed sensing, resulting in shortening the time needed to acquire and transfer the data and thus leading to reduction in power consumption.

3 Wireless Communication Technologies

The current massive development of wireless communication technologies is a response to unceasing demand for their use in practice. There are several standards that meet the requirements of our network. They are mostly low-power radio networks such as ZigBee and Bluetooth as well as other systems such as Wi-Fi, GSM, etc.

Despite the continuous trend of increasing transmission speed, these communication technologies with low data rates and low power consumption represent huge and successful development in forestry.

It is advised to use ZigBee communication standard in these networks, which provides the transmission speeds up to 250 kbps and a range around 100 meter in the basic version and up to 1500 meter in Pro version. High reliability and long battery life (several years) makes it suitable for creating this type of network in the forest environment.

4 Network Sensor Module

Proposed communication network basically consists of a distributed system of intelligent sensor modules with elements of versatility and adaptability. The main task of the module is the collection of information from sensors in the environment and sending them through the network to a remote computational centre. Sensor modules should cover a wide range of functions, which are often used in forestry. The internal structure of this module is shown in block diagram (Figure 2), and includes information processing and energy management parts.

The sensor module offers processing power of microcontroller (MCU) which manages scanning data from sensors, processing of these data and sending them in a suitable form for further processing by high-frequency radio module. An important task is the organization and optimization of network traffic for example using fuzzy control and power management in cooperation with the energy management circuit. This circuit provides energy harvesting and also the storage and distribution of the accumulated energy. Recently, technologies have emerged, which support wireless transfer of small quantities of energy. This can serve to create a certain kind of energy channel for wireless power transmission.

4.1 Network Management

Advanced method is the use of fuzzy control (Figure 3) in decision-making processes and determining optimal communication paths and power management. This type of control uses humanlike logic and is suitable for use in situations where the output parameter is influenced by several input parameters. As input parameters in this case, we can use for example path length, path load and energy consumption of communicational devices. The output in this case will then be the parameter determining the route metrics. Using this parameter it is then possible to establish the optimum route chart.

4.2 Energy Harvesting

Energy harvesting (recuperation) from the environment is a relatively new scientific discipline that deals with the collection of small quantities of en-

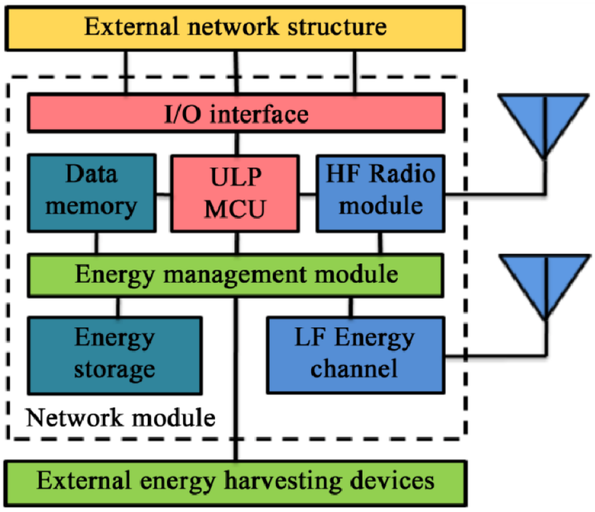

Figure 2 Block diagram of network sensor module.

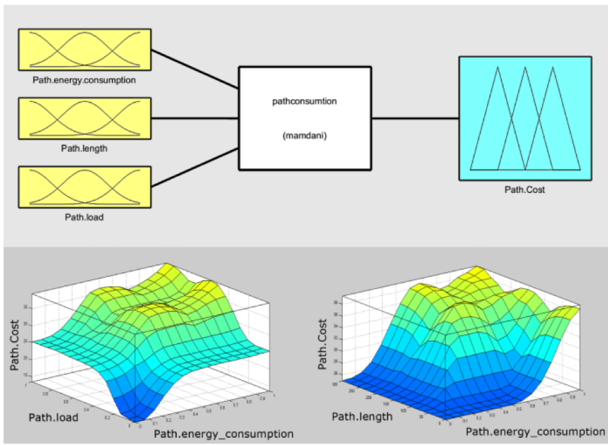

Figure 3 Example of fuzzy control for determining path metric.

ergy dissipated in the surrounding environment. In the domestic, work or forest environment many different kinds of energy can be found in many different forms such as light, heat, vibration, fluid flow, etc. [1]. Similarly the EM fields, which the environment is currently overloaded, can serve such a

Table 1 Alternative energy sources [1].

Energy sources	*Description of sources*	*Efficiency*	*Power gain*
Mechanical vibrations industry/organisms	Frequency 1 to 1 kHz Acceleration 1 to 10 $m \cdot s^{-2}$		100 $\mu W/cm^2$
Photovoltaic energy	Exterior 100 mW/cm^2	10 to 24%	10 mW/cm^2
	Interior 0.1 mW/cm^2	10 to 24%	10 $\mu W/cm^2$
Thermal energy	Industry 100 mW/cm^2	3%	10 mW/cm^2
	Organism 20 mW/cm^2	0.1%	25 $\mu W/cm^2$
EM field 0.9 GHz	0.3 $\mu W/cm^2$	50%	0.1 $\mu W/cm^2$
GSM 1.8 GHz	0.1 $\mu W/cm^2$		
EM field, Wi-Fi	10 $\mu W/cm^2$	50%	0.01 $\mu W/cm^2$

purpose. Different types of energy sources with their energy gain are shown in Table 1.

These energy sources can be converted into electricity using micro-generators of electric energy. These consist of physical-electrical converters, which generate low levels of voltage. To power CMOS electronic circuitry it is necessary to increase the voltage levels for them to operate correctly. Management of power supply and distribution for application circuitry is covered by power management circuit.

An example is the thermoelectric micro-generator which uses the Peltier module for generating voltage from the temperature difference and specialized power management circuit as converter of voltage levels, which serves for the collection, storage and distribution of electricity.

4.3 Energy Accumulation

In terms of alternative environmentally friendly energy storage, there are several systems that can be used. These systems currently represent modern and advanced technology, which is also reflected in their price, yet they have found their application in various fields, which require the use of clean energy sources. One of the most publicized alternative energy sources is hydrogen, which in combination with fuel cells appears to be the energy source of the future. Thanks to hydrogen it possible to store large amounts of energy for a long time without losses.

Another environmentally friendly method of energy storage is the replacement of batteries for supercapacitors, which are sufficient to power low-power devices and is often used for example in solar systems. Their main

Figure 4 Hydrostik fuel cell [2].

advantage is fast charging and the ability to deliver large amounts of energy in a very short time. The downside is less stored energy per unit of mass.

4.3.1 Accumulation of Energy by Hydrogen

Hydrogen is an ideal element that can be used for energy storage. Due to the existence of fuel cells hydrogen can be used as a power source and due to the existence of devices such as reversible fuel cell or PEM electrolyzers, it is possible to store energy in hydrogen form. For a long time the safe storage of hydrogen for later use was difficult. Currently, there are ways to store hydrogen in stable solid form (such as Hydrostik from Horizon fuel cell technologies) without the danger of explosion. This is a battery-like device (Figure 4), which contains a special metal alloy that allows hydrogen to be stored in a solid-state. This device provides 15 Wh of energy [2].

4.3.2 Accumulation of Energy by Supercapacitors

Unlike ordinary batteries supercapacitors store energy in an electric field and not in a chemical reaction. Through the use of advanced materials and due their inner construction, supercapacitors can store large amounts of energy.

Compared with ordinary batteries they achieve a much lower density of energy conservation. It is possible to use them in applications with low power requirements and systems using energy harvesting from the surrounding environment. Such systems allow their use for short-term energy storage. They

Figure 5 Supercapacitor/Ultracapacitor [3].

are also used in combination with fuel cells in many industrial applications [4].

4.3.3 Independent Energy Channel

Advantageous technology is creating a parallel energy transfer channel to the existing network topology. This channel would allow the transfer of electricity wirelessly between communication modules. An example of wireless transfer of electrical energy can be "WiTricity" (invented by a team of MIT physicists, led by Professor Marin Soljacic). This principle would allow the transport of electricity from modules with a higher energy gain to modules with a smaller energy gain and more power consumption. This system is ideal in environments where independent power supply system is used and allows energy harvesting from the environment [5, 6].

5 Application Possibilities and Advantages of the Network

It is possible to formulate a number of areas in which our concept of wireless eco-friendly sensor networks can be fully implemented:

- *Monitoring of Environmental Quality* – where relevant data (e.g. pollution levels, the presence of hazardous elements, etc.) is mostly collected at the monitoring stations.

- *Monitoring of meteorological parameters* – will help to produce quality information on the meteorological situation in the area. It can help to identify the conditions for the protection of forests and countries, but also in the evaluation of conditions for overpopulation of pests in forests.
- *Monitoring of wildlife migration* – The issue of wildlife migration monitoring is especially important for animal species protection. Based on the knowledge of the territory it is possible to create new protected areas or increase/decrease the existing level of protection.
- *Alert and early warning mechanism* – forest fires, earthquakes, landslides, volcanoes, floods... Dangers of forest fires are currently being monitored in several European countries. These systems are not yet connected to other systems for monitoring extraordinary events. If we implement a system for monitoring of multiple natural disasters, it will give us the possibility of creating a coherent universal protection system in the country against extraordinary events.

6 Benefits and Contributions

The contribution from the project will be in several areas:

- *Theoretical field* – to acquire new knowledge of energy-independent networks with energy generation from renewable energy sources such as solar and wind energy, mechanical vibrations, heat and others.
- *Methodological and educational field* – aims to bring new knowledge about energy-efficient eco-friendly wireless networks.
- *Field of implementation*
  - Outcomes of the project will be publications directly for practice, but also for theoretical, pedagogical and research sector.
  - Design networks models which will use different energy sources for its operation.

7 Conclusion

The proposed self-managed low-power wireless network can be used in the data acquisition system from the environment and transmission of different types of digital data. Application possibilities of this network have the ability to create high added value in quality and quantity of valuable data obtained from multiple devices. The proposed network is able to deliver useful knowledge in predicting and monitoring of extraordinary events, environmental and wildlife monitoring and early warning systems.

Based on the international exchange of experience in this project it is possible to create unified system for evaluation and processing of meteorological data, data from climate changes, early warning systems and others. This synergistic effect of uniform evaluation and processing system is an important added value of our project.

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Biographies

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