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Harvesting Energy from Trees in Order to Power LPWAN IoT Nodes

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***Abstract*— Low Power Wide Area Network (aka LPWAN or LPWA or LPN) nodes are important components in the IoT chain. They allow energy-efficient wireless communications between elements that can be several kilometers apart. This in turn should enable energy savings and facilitate the deployment of energy autonomous devices. However, energy autonomy is still in its infancy, as far as LPWAN is concerned. Most nodes run on mains or batteries. Mains seriously limit the mobility of the nodes and are only used in special cases. Batteries often lead to maintenance costs issues. Scavenging energy from the surroundings to achieve energy autonomy is an alternative that has hardly been used for LPWAN systems. In cases where energy harvesting has been used, solar energy has been the most popular source. Other methods are possible and could even be important alternatives. In this work we harvest energy from trees using TEGs. That energy is stored and used to power a long-range wireless embedded system (LoRaWAN in this case). Tests made for several months have shown that this method works well. Enough energy is harvested in all seasons, allowing sensing and transmission of data several times per day.**

Keywords—TEG; energy harvesting; power management; LPWAN; LoRa; LoRaWAN;

I. INTRODUCTION AND MOTIVATION

The clear majority of LPWAN nodes run on mains or batteries. Mains seriously limit the mobility of the nodes and are only used in special cases. Batteries often lead to maintenance costs issues, especially when one wishes to “install the node and forget it” for several years. Scavenging energy from the surroundings to achieve energy autonomy is an alternative. However, for various reasons, this has hardly been used for LPWAN systems. It is therefore important to consider how to advance the state of the art in powering LPWAN systems with harvested energy.

Compared to short-range wireless systems, LPWAN nodes such as Sigfox or LoRaWAN require hundreds of times more energy to transfer the same amount of data [5]. One reason is the low data rate that is used in order to achieve the transmission range. Consequently, it is more difficult to apply energy scavenging to such systems than to systems such as Bluetooth Smart.

Another critical issue is that of finding the appropriate energy source and fitting storage elements. The amount of energy and the reliability of the source are important to ensure that the system works when needed. So far, solar cells have been the main harvesters for LPWAN systems [1,9]. They have some limitations.

- Electrical energy is obviously only available when there is light. The cell should therefore be so placed that sufficient light falls on it. In the best cases, the cell will roughly collect energy for half of the day if they are outdoors. This depends of course on the geographical position and the time of the year. The storage element covers the period when the illumination is no longer appropriate. The characteristics of the storage should match the energy requirements of LPWAN nodes for that that outage period.

- Depending on the location, dust, snow, birds dropping can cover the cell and negatively impact the amount of harvested energy. Over-dimensioning the cell helps and increases the costs. This is a serious issue when cells are small, and node costs are important (the case of LPWAN).

- The type of energy storage used should suit the energy harvesting process. Long interruptions require storages with higher capacity. Storage elements are however one of the weak elements in the chain. Their performance is related to temperature, which is an important issue for outdoor systems. Furthermore, storage elements are affected by the number of charge/recharge cycles. Their impact on the environment should also be taken into account. It is beneficial to keep the storage minimal.

We use TEGS as harvesters (taking advantage of the temperature difference between the tree trunk and the ambient air). The temperature inside the tree changes slowly, compared to that of the ambient air. As the sun rises and sets, the air temperature goes up and goes down. It means that every day, there will be temperature differences between the ambient air and the tree trunk. That difference can be unipolar or bipolar, depending on regions and seasons. Contrary to solar cells, energy can therefore be harvested day and night, as long as the temperature variations are high enough. The harvested energy (electrical) is stored and used to power a long-range wireless embedded system (LoRaWAN node in this case).

There are several reasons that motivated us to use a TEG. Some of these reasons can be deduced from what is written above. There is more:

- Energy is abundantly available in form of heat. It is therefore important to try to harvest from heat sources. Clearly, temperature differences are needed in the case of TEGs. The fast variations of the ambient air temperature (day and night cycles) against the more stable temperature of a tree ensure that there is a good potential.
- Contrary to small solar cells, TEGs are less susceptible to dust, snow, birds' droppings. They will therefore fit in areas where solar cells cannot be used. That robustness also means that less maintenance work is needed. Growing leaves will also be less of an issue.
- TEGs are currently more expensive and less efficient than solar cells. Several past attempts to reduce their costs ended in failure. However, the costs for TEG solutions are going down. There have also been important progresses for the associated electronics (low-voltage boosters). They are therefore likely to become competitive in the coming years.
- Energy is stored in as heat in the elements in contact with the TEGs. It can be kept in that form until needed. One can therefore afford to keep the cost of storage elements low. This is an important advantage. Less expensive and more robust storage elements can be used.

There are several potential applications for LPWAN nodes that are powered in that way. The method can be used where appropriate trees are available. For instance, in agriculture and smart cities applications. Such nodes could be installed on trees in a wood in order to monitor air quality or other parameters, log the data and transmit it to central stations for evaluation. One could also imagine the use of Bluetooth Smart as wireless systems in order to transmit information to the smartphone of wanderers.

In this work, we first selected some trees for our proof of concept. An energy-optimized LoRaWAN node was then designed and evaluated, with the purpose of minimalizing its energy requirements. The harvesting system was designed with the appropriate TEGs, boosters and associate low-power electronic. After completing the design (hard- and software) the needed electronic boards, were produced and installed.

Our measurement setup has been running for several months, allowing us to collect enough data in the region of Winterthur (Switzerland) to cover several seasons.

II. STATE OF THE ART

There have been various attempts to harvest energy from trees. Methods using a mechanical mass or chemical processes [6,8]. However, we know of only one work that uses TEGs [7]. It is a basic proof of concept. The authors measure temperatures inside trees up to a depth of 10cm and apply the temperature differences to a testing platform where a power of 112 microwatt at 7 degrees differences was measured. Our understanding is that no load was powered by this energy source.

In this work (which is based on a Master Thesis) we go beyond what is known by effectively designing and building a system that is directly mounted on the tree.

Issues and details related to the type of tree, the effect of drilling, inserting a screw in the tree, the low-power stack, unipolar/bipolar harvesting … will not be discussed here. We limit ourselves to a succinct presentation of the system and of the results.

III. SHORT DESCRIPTION

Fig 1 shows a basic block diagram of the design. There are 2 important subsystems.

- The energy harvesters, the boosters, the storage, the power management electronics. The boosters can work with signals as small as 10mv and even less. Positive and negative temperature differences both lead to energy conversion.
- The microcontroller, the LoRa radio, appropriate communication stack and memory elements. As microcontroller, a very low-power device is used. Comparisons with existing LoRa embedded systems have shown that our system requires less energy

An aluminum screw is used to transfer the temperature of the trunk of the tree to one side of the TEG. The other side of the TEG is in contact with the ambient air, thanks to an appropriate heatsink.

The system uses a low-power sensor to measure humidity, temperature and air pressure. The voltage level of the supercapacitor storage element is also measured and transmitted.

Once the storage voltage reaches a preset value, the embedded system is started. Measurements are made, and the results transfer to the server using the LoRaWAN protocol. The spreading factor (SF) number are automatically adjusted, depending on the proximity of the gateway. In some cases, we forced this to SF12 and worked with maximal TX power in order to test the limits of the system. In such cases, the radio transmits with maximal energy, giving the longest range and highest energy consumption.

A battery-powered system was built in parallel to the EH-powered device to allow the monitoring (and verification) of parameters that are important for harvesting the energy. That system measures temperatures at different positions and depths in the tree and outside.

IV. EVALUATION AND RESULTS

The results of the tests are shown in form of diagrams below. The reader is advised to refer to the comments associated to the diagrams.

V. CONCLUSION

In this work, we have designed a low-power LoRaWAN sensor that is powered using temperature differences between the tree and the ambient air. A small hole is needed in order to bring one side of the TEG in thermal contact with the inside of the tree. This means that the method is not suitable for all trees. The measurements started at the end of 2017. The system has already been tested for several months. The results collected so far show that this method can be reliably used to monitor parameters in remote places and to send results several kilometers away. Enough energy is harvested to transmit tens of frames every day. By using the lowest spreading factor, the range is smaller, but more frames can be sent.

The lessons learned so far will be used to improve the harvesting system. A new design is planned, with an improved harvesting system and firmware.

ACKNOWLEDGMENTS

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REFERENCES

[1] Powering Long Range Wireless Nodes with Harvested Energy
Wireless Congress 2016; M. Meli, P. Bachmann;

[2] About LoRaWAN
https://lora-alliance.org/

[3] LoRa transceivers
https://www.semtech.com/products/wireless-rf/lora-transceivers

[4] About Sigfox
https://www.sigfox.com/en

[5] Limitations of Current LP-WAN Systems
Wireless Congress 2017; M. Meli, R. Kraeuchi

[6] R. C. Johnson. Tall tale: Trees could power wireless networks.
EE Times, September 2008

[7] C.P.S.et al. On Harvesting Energy from Tree Trunks for Environmental Monitoring. Department of Electrical Engineering, Federal University of Paraiba, May 2016.

[8] Voltree Power. Voltree Power - Bioenergy Harvester, 2016

[9] D. A. Wixted. LoRaWAN Energy Performance and Ambient Energy Harvesting. Glasgow Caledonian University, July 2017

Fig. 1 Basic block diagram of system. An aluminum screw is used on one side of the TEG, allowing energy transfer with the trunk of the tree. On the other side, a radiator in contact with the ambient air. The electrical energy from the TEG is boosted and processed to deliver characteristics that are suitable for powering the embedded system.

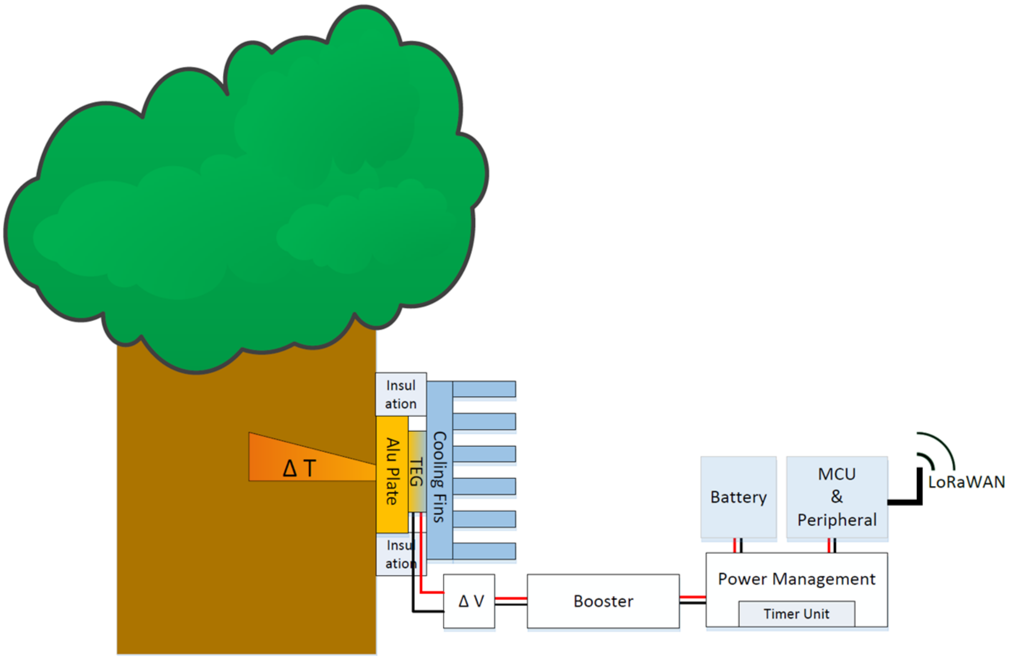


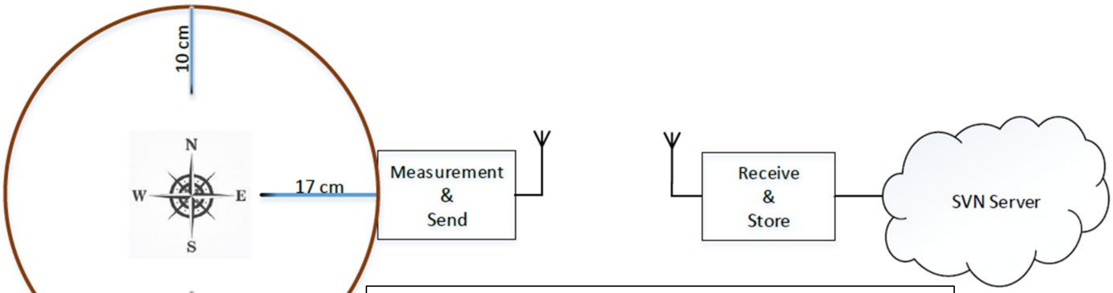
Fig. 2 The embedded system powered by EH is fixed to a tree. A wireless board with a LoRa transceiver is connected to the microcontroller board. The system is housed in a water-tight enclosure, designed for **outdoors uses**.

Fig. 3 Tree in the field with measuring system

A node installed on a tree

an aluminium screw is used to connect the inside of the tree to a side TEG.

Fig. 4 Set-up for measurement.
Data is collected and transferred to a server by 2 systems. The energy autonomous system has some sensors. There are also several sensors in the tree, at different depths and orientations. A monitoring/verification system powered by batteries measures the temperatures and transfers the data to the server



The position of the external radiator is important. Its exposition to sun radiations influences the temperature of one side of the TEG

Fig. 5 Measurements from mid-April 2018 to mid-October 2018. The data comes from the EH-powered system and from the battery-powered temperature monitoring system.

a) The transmission and the storage voltage, the relative current after the harvester and booster, air pressure, relative humidity and temperature are measured and transmitted by the EH-powered system. (graphs 1 to 5).

b) The different temperatures in the tree and outside come from the battery-powered system (6^{th} graph).

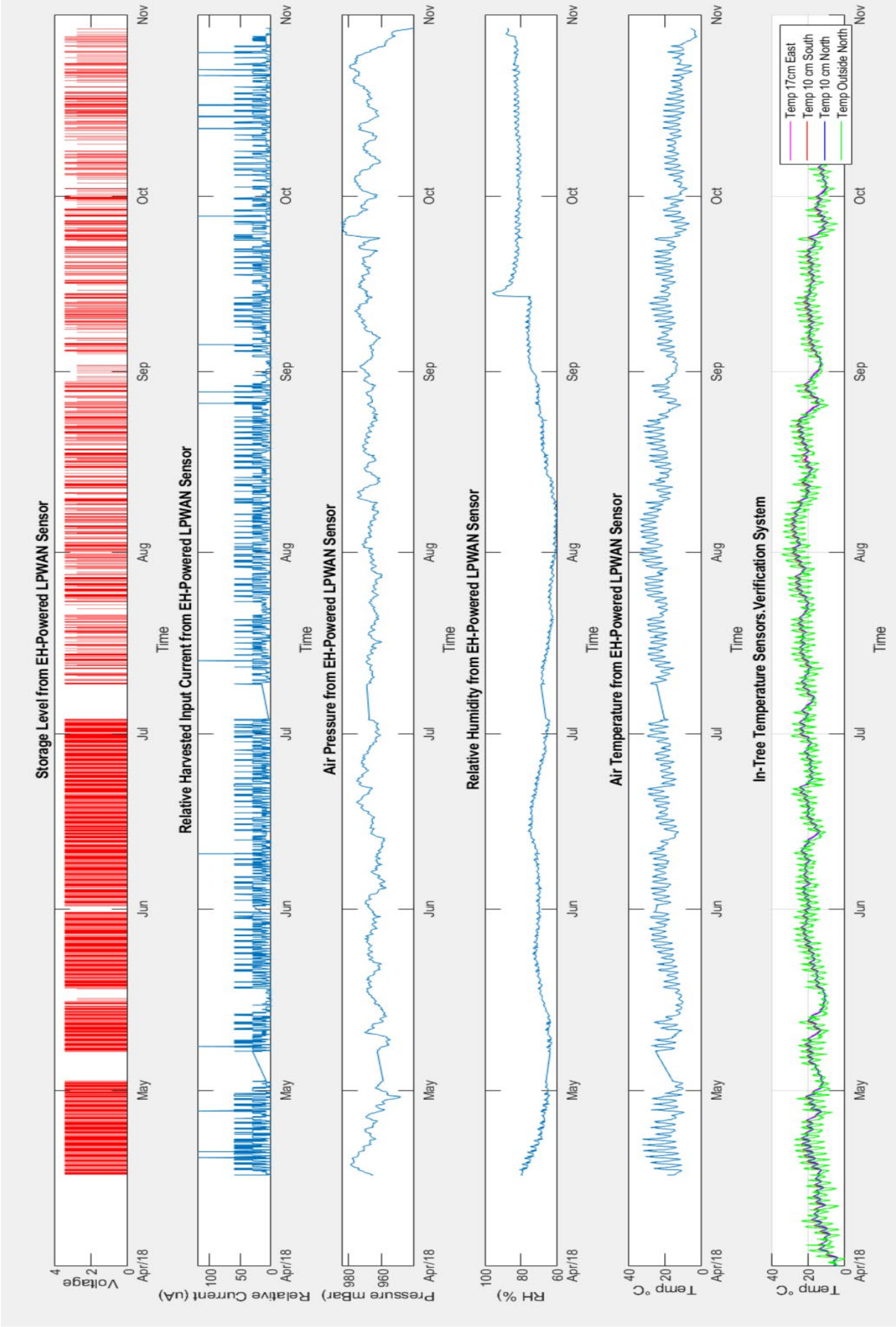


Fig. 6 Each of the red lines (graph 1) represents a LoRa transmission from the EH-powered system that has been received by the gateway. The height of the line shows how much energy is still in the storage elements. The closeness of the lines expresses the nearness of the transmissions and therefore how often the system transmits.

The blue lines on the second graphs are a relative measurement of the harvested power (or energy at the booster input). The green lines (graph 3) show the variations of the air temperature.

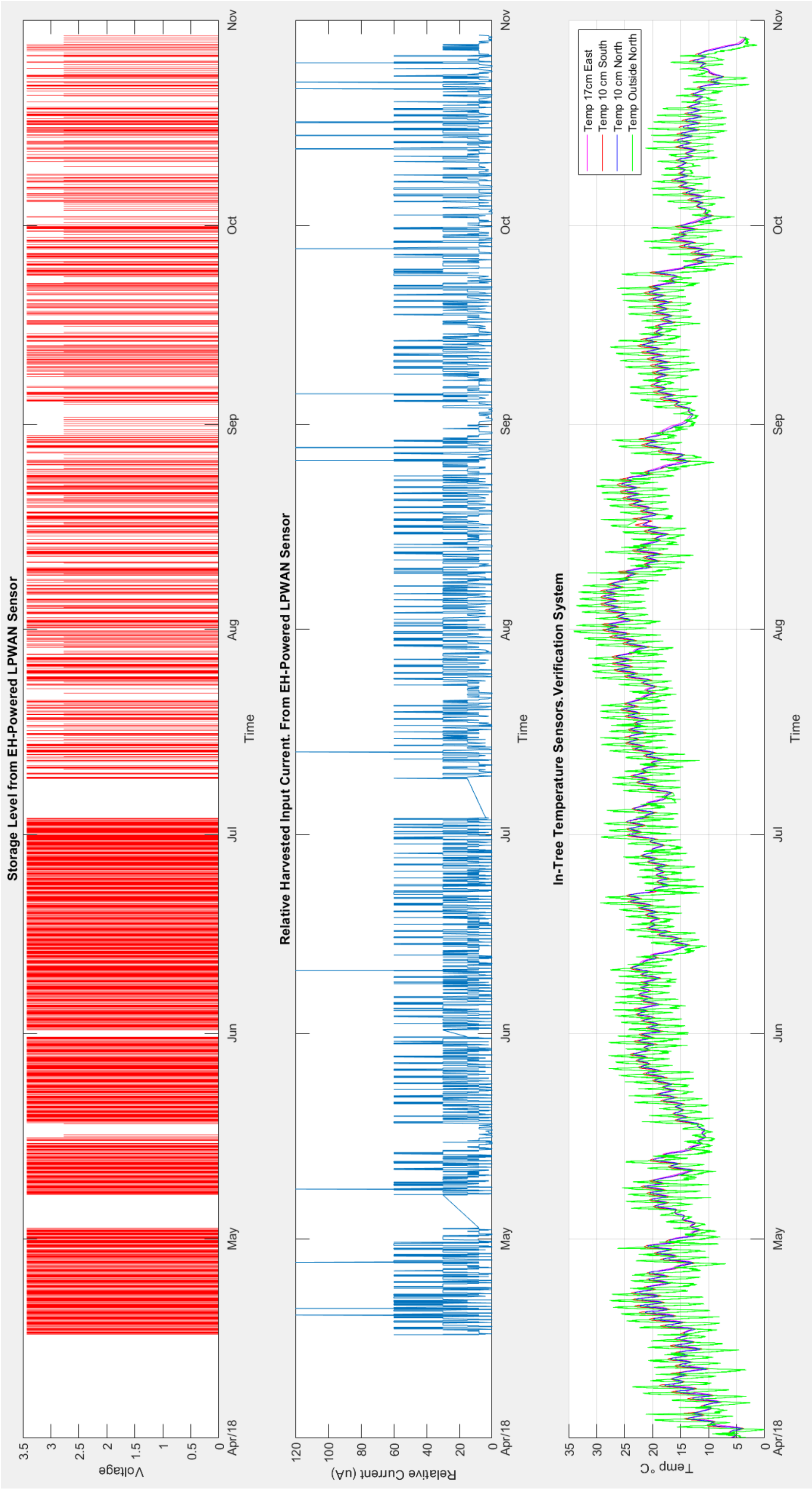


Fig. 7. Zoom on September 2018. The relation between the harvested power and the frequency of the LoRa transmissions can be clearly seen. High density of the red lines (LoRa transmissions) coincides with the power harvesting peaks. The system has enough energy to transmit a frame every 15 mins. Otherwise, there are about 2 hours between the transmissions, or there are no transmissions. The storage voltage is regularly measured to decide if the system should wait for 2 hours (harvest more energy) or transmit at 15 mins interval.

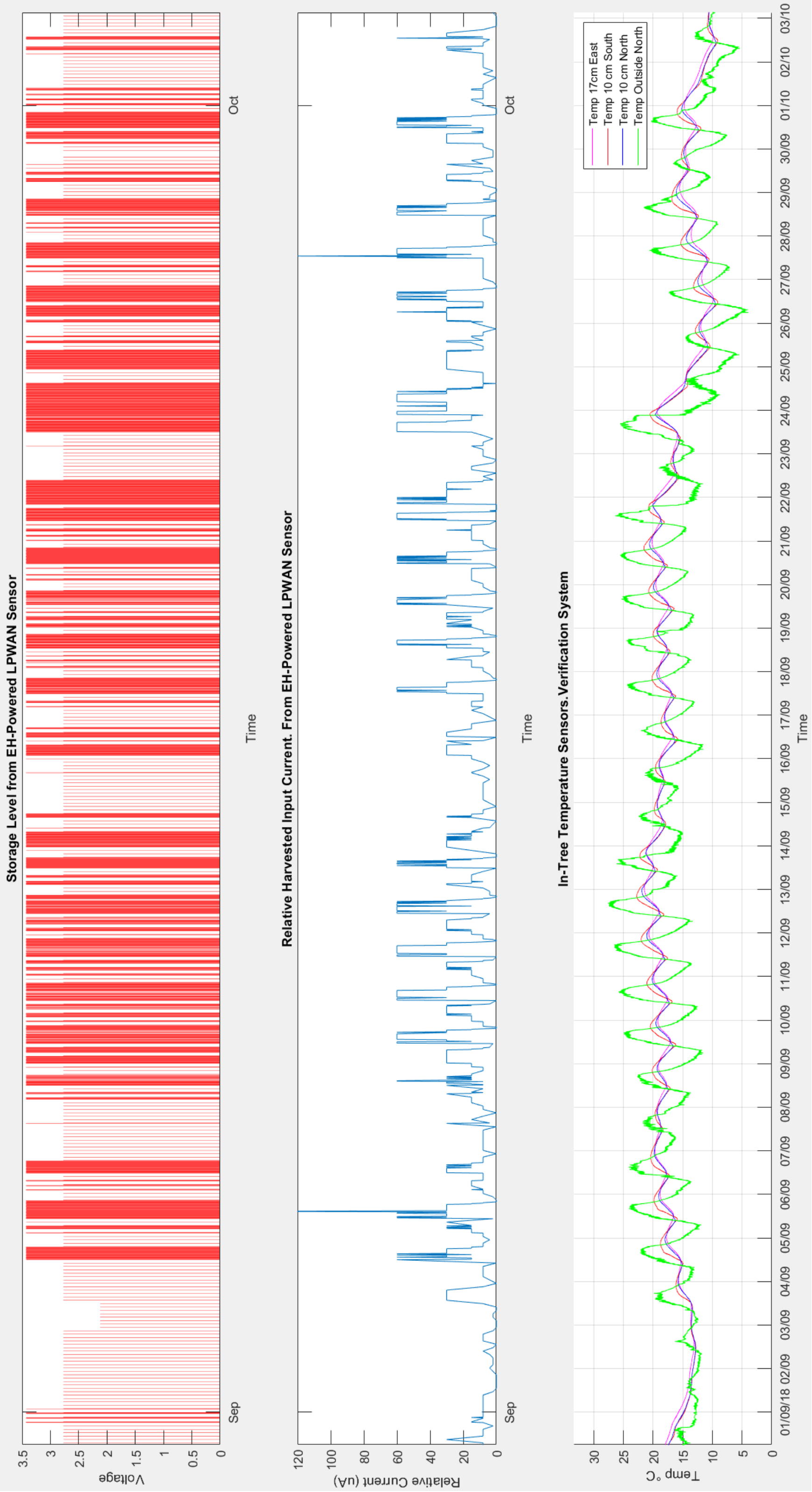


Fig.8 Zoom on 17th , 18th , 19th September 2018

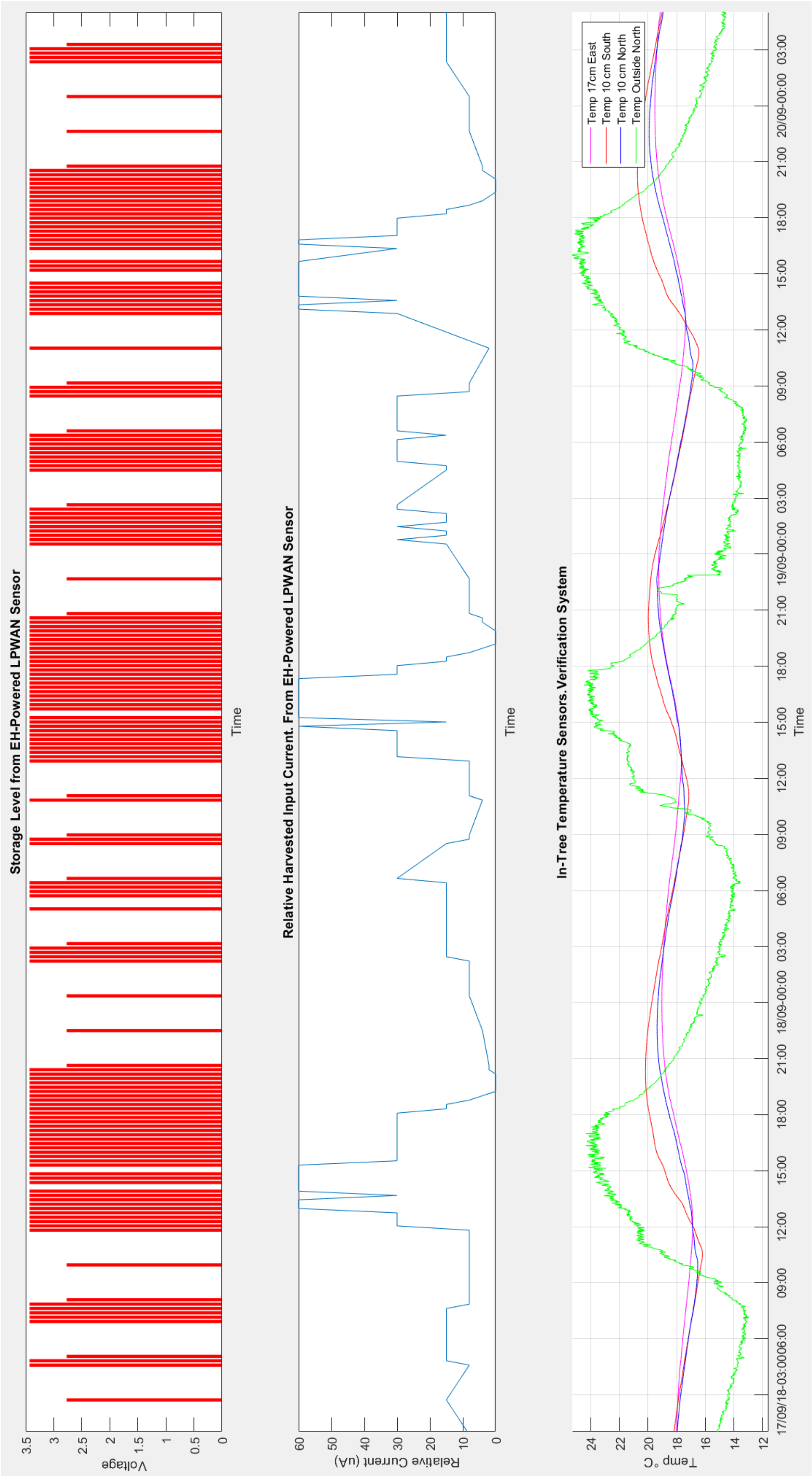
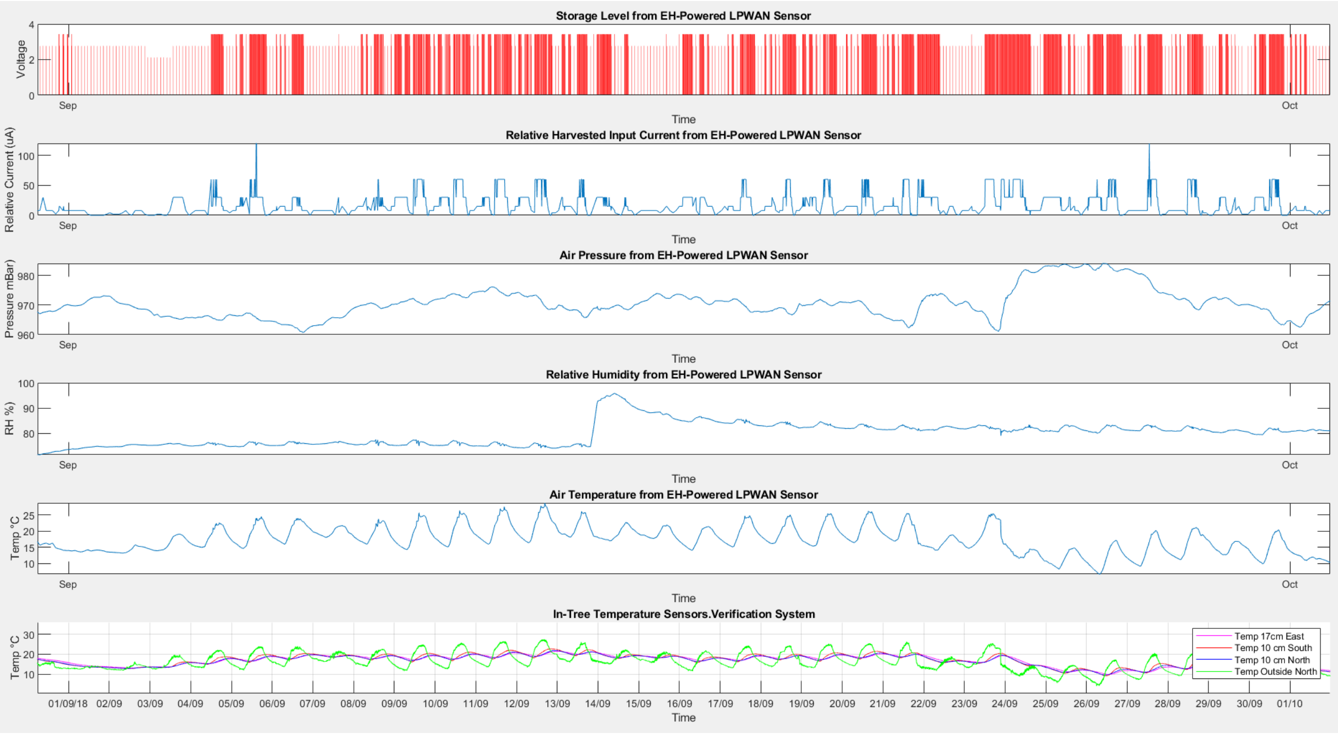
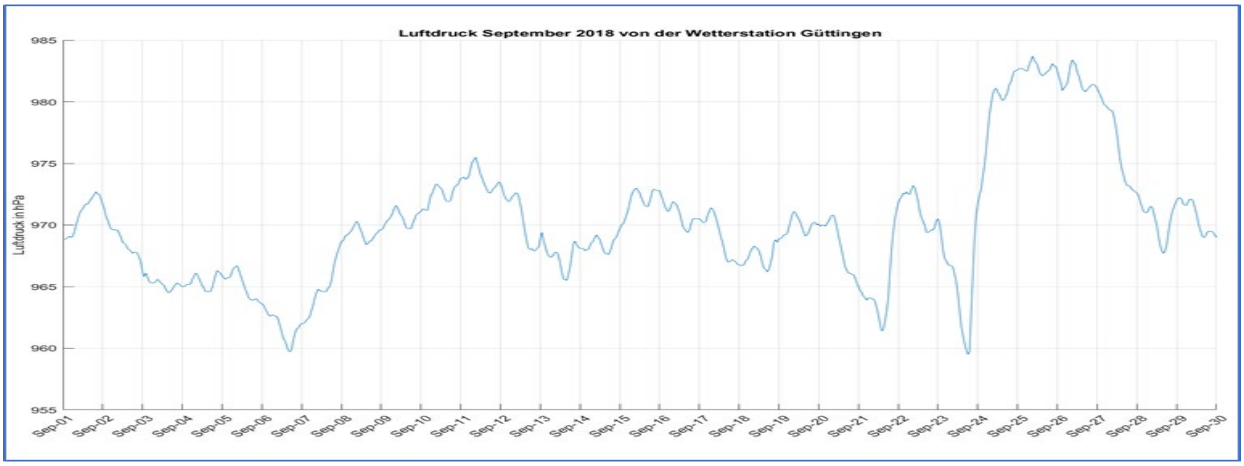


Fig. 9 Sensor measurements compared to weather station measurements (month of September 2018). As expected, the air pressure and temperature show striking similarities.





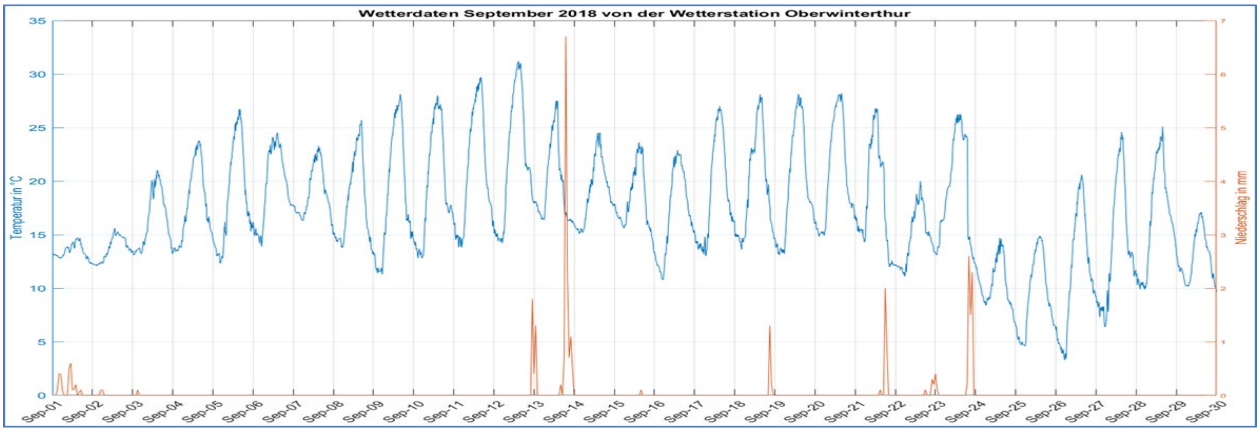


Fig. 10 Spreading factor and number of frames transmitted per day are shown along with the corresponding transmission and voltage level on the storage element.

- From April to July, a variable spreading factor was used, which was automatically adjusted to match the quality of service between gateway and sensor. SF8 and SF9 were often selected, leading to less energy consumption and therefore more frames could be sent (often >100 per day)
- From mid-July, SF12 was forced (automatic adjustment stopped), resulting in longer frames, better range, and more power. Consequently, less frames were sent per day. On average, the number of frames sent is still enough for applications requiring about 10-70 communications frames per day.
- There is room for optimization by using a supercapacitor with higher capacity.