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A wireless sensor network to monitor and protect tigers in the wild

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ABSTRACT

This paper investigates the possibility to efficiently use a wireless sensor network (WSN) to help preventing poaching in tiger habitats and to identify tigers' movement patterns that later on can provide valuable information about their territorial behavior, hunting and reproduction. The same method can be successfully applied to track other mammals in the wild. We concluded that these objectives can be achieved in a 2000 sq. km area with only 2000 module sensors that work in the ZigBee standard, that operates on the IEEE 802.15.4 physical radio specification.

1. Introduction

A traditional means for pursuing wildlife conservation is the establishment of protected areas – which at present time occupy a surface of about 5 million sq. km (about 3% of the total living area) – and protect the fauna inside, as human activities are prohibited or controlled, with a view to safeguarding particular species or species' habitats. Such a particular species is Panthera tigris spp: tigers were extirpated on the island of Bali in the 1940s, around the Caspian Sea in the 1970s, and on Java in the 1980s. Loss of habitat and the persistent killing of tigers and tigers' prey precipitated these extirpations. Nowadays there are less than 3500 in the wild but the illegal selling of their fur, bones or body parts is continuously decreasing their number, as shown by Traffic International, a worldwide monitoring of wildlife: in the 20th century the number of tigers decreased from 100,000 to a few thousands. Since 1987 the tiger was considered an endangered species but still more than 1000 tigers were illegally killed between 2000 and 2010 (Traffic website, 2013).

Adult tigers lead solitary lives, occupying a wide range of habitat types with a special preference on denser vegetation, such as forests (Novak, 1999). They establish and maintain home ranges: a tigress may have a territory of 20 sq. km, while the territories of males are much larger (about 60 sq. km), and congregate only when special conditions permit (such as plentiful supply of food). They have been studied in the wild using a variety of techniques: population estimates were made using plaster casts of their pugmarks – but the method was criticized as being inaccurate by Karanth et al. (2003) – using camera trapping instead, radio collaring (which seemed to be not as efficient as animals generally tend to destroy the mounted devices), etc.

In literature are mentioned a few other projects for animal monitoring – e.g. ZebraNet (Zhang et al., 2004) – which had low scalability (the maximal envisaged number of the deployed animal mounted nodes was 30) and involved human labor. The presence of humans might also influence the animals' behavior thus compared with the traditional techniques of animal monitoring, wireless sensor networks technology is a very promising green technology for the future. Similar animal tracking projects, but less complex, are: the Electronic Shepherd (Thorstensen et al., 2004), NEAT (network for endangered animal tracking) or TurtleNet.

The work presented here was driven by two goals: first, to help preventing poaching in tiger habitats by providing the means to alert local law enforcement of human presence in protected areas, and second, to provide valuable information about their territorial behavior, hunting and reproduction. We investigated the possibility to efficiently use a wireless sensor network (WSN) to achieve both objectives.

Wireless sensor networks (WSN) have drawn the attention of the research community in the last few years, driven by a wealth of theoretical and practical challenges, largely attributed to new applications enabled by large-scale networks of small devices

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capable of harvesting information from the physical environment, performing simple processing on the extracted data and transmitting it to remote locations.

WSNs have great potential for many applications in scenarios such as: military target tracking and surveillance, natural disaster relief, biomedical health monitoring, hazardous environment exploration, and seismic sensing (Yick et al., 2008), being implemented with IEEE radio standards such as: WiFi, Bluetooth, Active RFID, WiMAX, and ZigBee (802.15.4) (Labiod et al., 2007).

A WSN typically has little or no infrastructure as it consists of a number of sensor nodes (few tens to thousands) working together to monitor a region to obtain data about the environment. A sensor is an electronic device that is capable of detecting environmental conditions such as temperature, sound, chemicals, seismic waves, infrared, still/motion videocamera or the presence of certain objects and may be organized in clusters such that a locally occurring event can be detected by most of, if not all, the nodes in a cluster. Progress in microelectronics made possible the development of cheap, small dimension detecting equipments that use little energy: being equipped with a microprocessor, memory, battery and the capacity to transmit on a radio channel, these devices can combine the detection, processing and transmission functions in a small device called a *sensor module*.

Even though a sensor has small processing capacities, its ability to communicate with other sensors increases its capability to execute tasks much more complex then detection and transmission of information making the sensors able for involvement in real time processing of data collected distributed facilitating control, calculating and interrogation applications. Distributed processing is more efficient from the energy consumption point of view because the transport of data on long distance is avoided. Moreover, data processing is made only among neighbor sensors thus the number of data transmission between sensors is reduced (even more energy saved) (Chandra et al., 2008) and a further advantage is that no matter the nature of the network (ad-hoc or centralized), each sensor in it knows its neighbors thus in the case of malfunctioning the network can reconfigure itself easily.

An attempt to investigate if WSNs are suitable for wildlife surveillance was made in (Badescu et al., 2011) where the typical problems and limitations of the WSNs were analyzed and solutions presented, but only for a very small (500 sq. m) monitored area.

In this work we focused on simulating if an up-to-2000 sensors wireless network can be designed and configured to monitor the tigers in a 500 sq. km area in the wild, and also to signal to authorities the possible presence of poachers. We have considered the WSN solution due to various reasons: first, the network should work autonomously (being deployed in the wild) and for this purpose the sensors are perfect candidates as they are independent (they have incorporated the radio link and the power source). Second, in order to save energy, the collected data should be pre-processed on site because this avoids energy-consuming transmission of data on long distances and guarantees a quick response in case a poacher is detected: again sensors represent a good solution due to their data processing abilities (as an example, pressure sensors mounted at soil level can determine weight and this way it is possible to discriminate between the presence of a human or an animal). Finally, the sensors should be able to detect and signal the presence of poachers and, if the presence of a human is detected (e.g. by weight discrimination), a message can be immediately sent in the network toward the base station and the poacher can be intercepted at the location given by the position of the signaling sensor, as all nodes are able to determine their position in space (Swami et al., 2007).

A possible drawback of such a method is that radio electromagnetic waves used by sensors to communicate between each other and with the base station (that processes data and makes decisions) suffer attenuation due to the presence of vegetation. An efficient method to configure the WSN will be presented in the next section.

2. Method

In the following we will show that a wildlife area of 500 sq. km can be efficiently monitored using only 2000 ZigBee sensors positioned symmetrically near ground level. In a wireless network each sensor detects when a poacher/tiger is located in its proximity and the information is transmitted from neighbor sensor to neighbor sensor to the base station, where information is processed and decisions are taken. All sensors communicate with each other using radio messages transmitted on a 2.4 GHz frequency, corresponding to the ZigBee communication standard.

It is well known that forested areas where most tigers live produce near-ground propagation losses for radio signals due to various factors (like ground reflection, tree-canopy-reflection (Meng et al., 2010), etc.). This deteriorates the quality of the signal and introduces extra delays thus in order to assure an obstacle free propagation path we considered that sensors transmit their information not between each other (at ground level where the vegetation is rich), but to a flying unmanned aerial vehicle (UAV). By mounting the antennas of the sensor modules on top of the trees (~10 m above ground) the UAV will be in the antenna's direct line of sight: the propagation losses together with the near ground effects will be decreased and the integrity of the radio messages will be kept intact. The aerial vehicle re-transmits the information from sensors to a base station where the information is further processed and analyzed.

UAVs are a cheap an efficient way to monitor large areas, having a wide variety of shapes, sizes, configurations, and characteristics (UAV webpage, 2015). Historically, UAVs were simple remotely piloted aircraft, but autonomous control is increasingly being employed. The UAV can be controlled either autonomously by computers in the vehicle or under the remote control of a pilot on the ground or in another vehicle (the obvious solution for our application is the autonomous control that saves human labor). The aerial vehicles can even use photovoltaic cells as an energy source which reduces the fueling cost and increases their autonomy for longer periods (i.e. using this solution the area can be monitored continuously for as long as a possible experiment would last).

The investigations on the functionality and performances of the WSN were made using QualNet 4.5, a software program supporting scalable simulations of numerous types of wireless protocols. We considered that the 500 sq. km area is subdivided in three roughly equal regions: R1 of dimension 7 km × 25 km (with 700 sensors), R2 – 7 km × 25 km (with 700 sensors) and R3 – 6 km × 25 km (600 sensors). The sensors' distribution is chosen such as an area of 1 sq. km is instrumented with 4 sensors. We have designed a scenario that analyses separately each of the three regions R1, R2 and R3. In each region the information from the sensors is collected by a UAV that re-transmits it to a sole base station positioned in the center of the monitoring area. Thus the network consists of 2000 sensors, 3 continuously flying UAVs, and the base station. The communication channel between sensors and UAV is ZigBee technology, and the one from UAV-base station – WiFi. The WiFi standard allows the radio signals to be transmitted on longer distances, with the disadvantage of higher power consumption, however, neither the UAVs, nor the base stations are conditioned by power demands. In the simulation we have included the presence of a poacher that is moving in a straight line for 2 h (which is the time of the simulation).

The UAV was configured in the simulations according to the model SOIM I (AFT, 2013): IT has autonomy up to 120 min and a maximum speed of 220 km/h. The vehicles should cruise at an altitude of 50 m (this altitude was chosen to decrease the fuel