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Performance assessment of a kinetically-powered network for herd localization

Nelson I. Dopico *, Álvaro Gutiérrez, Santiago Zazo

ETSI Telecomunicación, Universidad Politécnica de Madrid, Avda. Complutense 30, 28040 Madrid, Spain

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ABSTRACT

Developing a herd localization system capable to operate unattended in communication-challenged areas arises from the necessity of improving current systems in terms of cost, autonomy or any other facilities that a certain target group (or overall users) may demand. A network architecture of herd localization is proposed with its corresponding hardware and a methodology to assess performance in different operating conditions. The system is designed taking into account an eventual environmental impact hence most nodes are simple, cheap and kinetically powered from animal movements – neither batteries nor sophisticated processor chips are needed. Other network elements integrating GPS and batteries operate with selectable duty cycles, thus reducing maintenance duties. Equipment has been tested on Scandinavian reindeer in Lapland and its element modeling is integrated into a simulator to analyze such localization network applicability for different use cases. Performance indicators (detection frequency, localization accuracy and delay) are fitted to assess the overall performance; system relative costs are enclosed also for a range of deployments.

1. Introduction

Animal localization has been an active research area for years. Animal behavioral studies (Bergman et al., 2000; Zhang et al., 2004), cattle monitoring (Schlecht et al., 2004), improvement of livestock techniques (Bailey, 2000) and other applications perform animal localization (Nadimi et al., 2008; Huircán et al., 2010). Different devices and strategies have been used throughout the years and, in particular, the use of GPS collars has been extended to moose (Rempel and Rodgers, 1997), camels (Grigg et al., 1995), goats (Buerkert and Schlecht, 2009) and other species. Frequently, accuracy is a must since such collars are required for fine localization or tracking. However, user requirements are not always the same and the aforementioned devices may exceed the budget of herders who could be satisfied with equipment offering less features. Thus, researchers and engineers may face a challenge consisting of developing alternative systems lowering costs and/or providing users with additional facilities. Developing such new systems comprises a number of stages besides the mere electronic design of collar-like devices. These stages can be, for example, on-field testing, modeling, simulation, performance characterization, etc., and developers can go through them several times before they come up with an acceptable system.

This paper studies and models an architecture for herd localization which can be adjusted to users' needs and extends node autonomy by replacing batteries with a kinetic generator. The authors' effort was primarily driven towards sustaining a traditional lifestyle in a natural environment: Saami herders and their semidomesticated Scandinavian reindeer, *Rangifer tarandus tarandus* L. Highlights and outcomes of their work are enclosed hereafter covering the system developed and a methodology and its tools for performance assessment. In such a context, the scheme followed can be particularly interesting for those working on herd localization systems, who can use it to evaluate new developments in preliminary phases of their work or refine the system presented.

The paper provides information regarding system elements along with their modeling. Likewise, a generic application scenario is modeled from measurements taken by the authors and from other studies in the same region and conditions (Mårell et al., 2002). Results outputted by an agent simulator tailored for such framework are studied for a wide variety of experiments, which allows to evaluate a wide range of operational modes. Simulation outcomes are then used to characterize statistically the system further by obtaining closed forms for a number of statistical estimations. Such knowledge is then used to determine system adjustments for two scenarios with different requirements as examples of its applicability. The system is, therefore, defined conceptually, analytically, and is enough detailed so that other scenarios–species, season, etc. – could be integrated and assessed.

2. Materials and methods

2.1. System architecture and operation

Three different kind of elements make up the network: primary nodes, secondary nodes and hotspots – see Fig. 1 or (Gutiérrez

* Corresponding author. Tel.: +34 91 5495700x4006.
E-mail addresses: nelson@gaps.ssr.upm.es (N.I. Dopico), aguti@etsit.upm.es (Á. Gutiérrez), santiago@gaps.ssr.upm.es (S. Zazo).

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et al., 2009) for a thorough system description. The equipment described hereafter is designed and manufactured specifically for our application. However, components are commercial off the shelf which can be purchased. Primary and secondary nodes are mounted on animals and are therefore mobile nodes, whereas hotspots may be static (then named base stations) or mobile – carried by an individual or vehicle.

Secondary nodes are the simplest elements in the network and are powered up by kinetic energy from animal movements. Their kinetic generator is made up of a hollow tube with a magnet inside and two coils on its ends – see Fig. 2. The generated voltage follows the Lenz law. The kinetic generator depends on the swing of the magnet inside the tube; therefore, its efficiency depends on its placement and the movement transferred to the generator. Moreover, secondary nodes do not integrate a sophisticated CPU, but just a PIC, a radio transmitter and circuitry to broadcast a unique ID or beacon.

Primary nodes, in turn, integrate a Global Positioning System (GPS) device – which can be switched on and off depending on the final application needs, a CPU, a receiver of secondary-node beacons and a transceiver to communicate with hotspots. They are battery powered.

A hotspot is a battery-powered node which has access to the Internet or another network that makes data available to the end user by means of a monitoring system. It has the same CPU, receiver and transceiver as primary nodes.

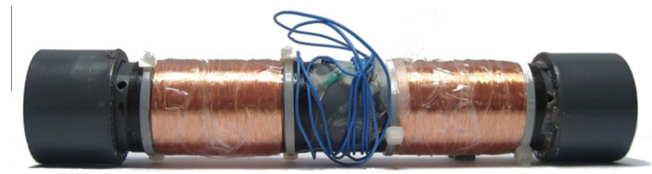

Fig. 2. Kinetic generator in secondary nodes.

2.1.1. Operation

The system operates in two stages, namely *Detection* and *Notification*. The first one corresponds to the operation up to the time on which a primary node detects the presence of a secondary node, whereas the latter refers to the notification of the previous detection to a monitoring system by communication between primary node and hotspot.

The aforesaid network components communicate over radio links which operate in two different bands. Secondary-primary links (secondary links hereafter) modulate their information in the 433 MHz band with a data rate of 4.16 Kbps. Primary-hotspot links (hotspot links hereafter) operate in the 166 MHz band and are able to reach up to 200 Kbps.

Communication over secondary links is enabled stochastically by animal movements. Such behavior is a consequence of the secondary-node simplicity which allows to have devices which are not battery powered. As the kinetic generator on secondary nodes harvests enough energy from animal movements, it powers up both circuitry and transmitter in order to achieve an ID beacon transmission. If a primary node is then within the transmission range, it receives and stores the transmitted ID. Communication over secondary links is unidirectional without medium access control. However, transmissions from secondary nodes are not expected to be very frequent (as it is explained later), hence beacon collisions do not impact dramatically on system performance.

A primary node which receives a transmission from a secondary node approximates such secondary-node position through its own location – indeed its last GPS reading. This stage is called *Detection*. While such primary node is moving in an environment, it fills out a table with the different secondary-node IDs received, assigned approximated position and the time when the transmission took place. *Notification* happens later: as the aforementioned primary node enters a hotspot communication range, it transmits to such hotspot all the information acquired from secondary nodes along with its own trajectory. A light protocol stack operates on each terminal of a hotspot link which allows for collisions, losses and manages retransmissions.

Depending on the characteristics of the final deployment, hotspots can be on fixed locations, can be carried by an individual or both. Once a hotspot receives data dumped by a primary node, it sends them to the monitoring system. Such monitoring system is expected to receive information from different hotspots, hence it will merge all the information and provide it to the end user.

Thanks to the aforementioned operation, the final system has information about position estimates of primary and secondary nodes. Therefore, it will be able to reconstruct roughly the trail of different animals carrying either a primary node or a secondary node. Note that such secondary-node trail reconstructions are approximations of the real ones as a consequence of the stochastic transmission of secondary nodes, the probabilistic reception of the primary nodes and, to a lesser extent, the discretization of the GPS readings. As already depicted, system operation and architecture pave the way for animal monitoring in outdoor environments, however derivative use to localize other goods, items or individuals

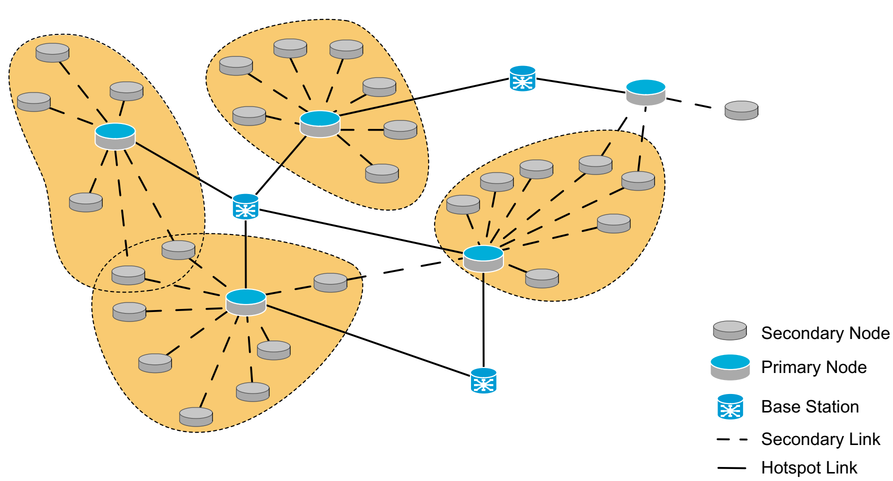

Fig. 1. Network architecture.