Ratpack: Communication in a Sparse Dynamic Network

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ABSTRACT

The goal of this project is to investigate the behavior of wild living rats using sensor networks. The main challenge with respect to communication is the sparse and very dynamic network determined by the burrow dwelling behavior of rats, which makes delay tolerant data transmission schemes a necessity. The physical and computional restrictions in embedded devices make routing an interesting challenge for which we are currently developing new strategies.

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1. INTRODUCTION

One of the core motivations for the research in sensor networks is the vision of wide spread deployment in nature to observe environmental phenomena. In the following, we discuss our contribution to make this vision a reality. With the help of custom sensor hardware, we plan to observe several aspects of rat behavior in their natural habitat.

Much is known about rat behavior in captivity as a sheer uncountable number of experiments have been conducted with them in laboratories. However, comparatively little is known about their natural behavior as they dwell in underground burrow systems. Previous research focused mainly on archeology like approaches, digging out existing burrows and determining behavioral patterns based on found remnants. Still, the burrows previous inhabitants usually flee from the site once the researchers start excavating it.

Our approach tries to give a more vivid view into the behavior of wild living rats. By equipping rats with sensor nodes, which form a loosely connected network, we plan to derive a time–dependent view of the behavior of rats and derive patterns previously unobserved or at least unconfirmed in the wild.

After discussing some related work, we elaborate on the scenario of our application and its impact on the node and software design. Finally, we present some approaches, we consider the most appropriate and then conclude the paper.

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2. RELATED WORK

Recently, a considerable number of sensor networks have been deployed for environmental monitoring [8, 9]. Most of these deployments – except ZebraNet[8] – are static networks. In these, researchers placed sensor nodes at locations of interest and ensured that the nodes could communicate with each other and the base station.

The researchers of the ZebraNet project strapped customized sensor nodes, equipped with a GPS receiver and a solar panel, to zebras. The nodes then recorded the animals' position as well as when and where they met. From this data, biologists evaluate the zebras' movement and social interactions. Unfortunately, GPS is not feasible for burrowing animals due to the relative impermissibility of earth to radio signals and its limited accuracy of about 15 m.

In the DTAG project [6], Johnson et al. analyze the behavior of whales. Since whales spend most of their time (up to 95%) underwater, radio communication is infeasible. Therefore, their approach is to record relevant data into flash memory and detach the recording tag from the whale, once the memory is full. The tag then floats to the surface to be collected by the researchers. Although this approach is very elegant for underwater animals, it is not feasible for research on burrowing animals either.

3. ENVIRONMENTAL CONSTRAINTS

Working with rats puts numerous constraints on the design of sensor nodes. One major limitation is their size: An average adult Norway rat measures 25 cm in length and weighs 250 g [2]. Our sensor nodes needed to be designed in a way that our animals would not be significantly restricted in their natural movements, which strongly limits the available node and battery size.

As for the behavioral restrictions, the most important one while studying rats is their burrowing. We confirmed in experiments with artificial rat burrows that the expected average communication range is 0.9 m along a typical rat burrow tunnel, l while through earth, this range can be as low as 0.2 m to 0.3 m. Consequently, these channel characteristics result in a sparsely connected network.

At the same time, memory capabilities are also limited by the size and energy constraints of our system. Hence, a trade-off must be found. As we do not expect to know all exits of a rat burrow and some rats may stay in the burrow for long durations, we cannot guarantee that each sensor node will be able to deliver its measurements to the base station before its memory is exhausted.

Figure 1: Norway rat equipped with sensor node

4. ROUTING

Currently, the main research focus in the sensor network community is on continuously connected sensor nodes. Thus, although the network topology may vary slightly over time, for example, due to node failure or changing radio conditions, the network infrastructure is anticipated to remain stable in these mostly tree-based or beacon-based routing protocols.

In our scenario, a delay tolerant approach[4] seems to be far more feasible. Data should be relayed from one sensor node to another when their bearers, i.e. the rats, meet. We place a base station at one (or more) exits of the rat burrow. When a rat passes along this exit, all measurements, e.g. data collected by this rat as well as the data received from other rats, are transmitted to this base station.

4.1 Utility Based Forwarding

Data being collected have varying relevance over time, depending on the status of biological insight. For example, in the beginning, the layout of the burrow system might have a higher priority, while later, the vocalization information might become more important. The utility of transferring one bundle of data might be determined by various factors such as: the availability of memory on another node, the expected delay of forwarding that data through a specific node to a base station, current energy levels. Depending on the current utility metric, different forwarding decisions can be taken[1].

4.2 Social Network Based Forwarding

Social structures in rat societies are expected to follow power-law, as is the case for most animals[7]. This fact can be leveraged if specific nodes need to be addressed. Similar to the famous Milgram experiment, if the receiving node is not known to a forwarding node, that data is forwarded to the node with the highest degree of neighbors, if there is no such node, random walk is used[3].

4.3 Data Reduction

Sensor nodes have very limited storage space, typically 4 kB of RAM and about 500 kB of additional flash space. As discussed, it may take some time until a certain rat passes one of the base stations. Thus, its sensor node needs to store potentially large amounts of measurement data – its own and that of the rats it has (potentially indirectly) met and was chosen to relay. Several ways to reduce the amount of memory necessary exist, among them: lossless compression of the data, using LZW or similar algorithms and lossy source coding schemes.

Our goal was to develop behavioral models which should be validated. Typically, these models require significantly less memory than the original experimental data. Therefore, another focus of our work is not the collection of raw data but rather the automatic derivation of models using techniques from the stream data mining community[5]. A limited amount of supporting evidence and outliers may still be transferred to give researchers some additional data.

5. LABORATORY PROTOTYPE

Our first setup consists of a mica2dot mote powered by a coin cell battery and supporting a number of custom made sensor boards (see figure 1). In our current laboratory prototype each node records data (e.g. data from accelerometer and ultra sound) until its memory is exhausted and subsequently transmits it to the base station when signal quality is sufficiently high. This approach is feasible in preliminary test scenarios in the controlled environment of a research center. For use in a real burrow system, however, this approach would need to be adapted for the reasons stated above.

6. CONCLUSION

In this paper we discussed the features required for an efficient and energy-aware communication paradigm that can be used for small rodent observation. Looking at the presented scenario, it becomes apparent that the necessary communication paradigms for sporadically connected networks are missing in the sensor network community. Currently, our work focuses on designing and implementing the required features. The main deployment scenario is rat observation, however, this architecture can easily be adapted to other species. Newly available platforms have become sufficiently small to make it seem plausible to even study animals as small as bats.

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