1 Introduction and Motivating Application

Marmots are a classical field of research for behavioural biology. These animals warn each other against predators and reveal complex behaviour patterns. In order to understand their behaviour biologists record and evaluate these alarm calls and their location. Because these cries are comparatively rare, unattended operation is desirable. Up to now, researchers have used wired sensor networks for that but they are relatively inflexible and hard to deploy.

The authors propose, describe and implement a custom wireless sensor network, which is significantly more flexible. Some special challenges were:

- Audio recording and processing is very intensive in terms of space and processing power: One needs a highly optimized pipeline.
- Pure recording of audio data is not enough: Marmot positions have to be computed in real-time, so that in-field biologists can capture additional information (e.g. which animal raised the alarm).
- Archiving of raw data: For algorithm tuning and for interactive use to re-play and re-analyze recorded data, biologists require also a “spill raw audio data to disc”-feature.
- "Out of the box": Since non-computer-scientists are the main users of the platform it should be easy to deploy, self-organizing and -configuring and easy to use in general.

2 VoxNet Platform

VoxNet is basically a classical wireless sensor network.

2.1 Nodes

Sensor nodes comprise essentially two 400 MHz ARM cores, 2x64 MB RAM, 8 GB flash memory, four microphones, a high-precision GPS module and a standard WLAN module. All components are encapsulated in a compact, robust box and operate for approximately 8 hours before batteries have to be recharged.

New nodes determine first their location per GPS and then integrate autonomously into the ad-hoc network. VoxNet uses an implementation of DSR (Dynamic Source Routing) as routing algorithm.

2.2 Software

VoxNet builds on the stream processing environment Wavescope and the associated WaveScript language and compiler. WaveScript programs are composed as a set of communicating stream operators (pipe and filter architecture / data flow architecture). Wavescope disseminated data flows according to the node capabilities automatically in the network. Time-consuming filter routines, like FFT or AML (Approximated Maximum Likelihood, the call localization algorithm), can be computed locally or remote on a processing server, depending on local node utilization.

The main part of the work was to adapt Wavescope to the resource-constrained embedded...
environment and to the sensor interfaces. For that the authors chose the aggressively optimizing, single-threaded StandardML backend. Furthermore they implemented another thread, which provides audio data and node status information as Wavescope data streams. A WaveScript spill-to-disc-filter can be leveraged to dump raw data on the internal flash disc.

For distributed processing, WaveScript is extended by the concept of network streams. Network streams provide the same semantic as local streams and can be used completely transparently. For more special purposes, two "lossy" network stream model implementations are also provided.

The control console constitutes the central point of management and is used for node registration, script compilation, program deployment, collecting results, logging and troubleshooting. With the help of a terminal application, users can control individual nodes. A slim Java application, which can be used from arbitrary network devices (e.g. in-field PDAs), visualizes Wavescope network streams in real-time.

For global time propagation they apply the RFB algorithm (Reference Broadcast Synchronization) and GPS time.

3 Performance and Evaluation

3.1 Microbenchmarks

The main focus was to validate the resource usage of a WaveScript implementation of the alarm call detection algorithm against a previous, hand-written C-implementation. Surprisingly, it turned out, that the WaveScope variant consumes 30% less CPU and 12% less RAM. Because of lower resource consumption, the authors could implement a concurrent "spill to disc" thread for the first time.

Another comparison showed that the WaveScript-implementation of AML is even a little faster than the C-implementation.

3.2 In-Situ Application Tests

In august 2007 VoxNet has been rolled out for the first time in large-scale in the Rocky Mountain Biological Laboratory. Across a 2.4 acres large area and over a period of seven days, eight nodes have been deployed.

In order to avoid potential problems with multi-hop communication they measured goodput for a single-hop setup in a first test. For that the gateway was equipped with a larger antenna. All nodes were instructed to send 32 kB (the size of a raw data unit) simultaneously to the gateway. The test revealed relatively equally distributed transfer times (about 0.6 s). Two nodes, which were situated most conveniently, required only half of the average time.

Subsequently, the same test was carried out within the self-organized multi-hop network. As expected, the goodput performance degraded with the number of hops: The most distant node (three hops from gateway) needed 10 times longer than the closest.

Another measurement addressed the question whether it is faster to do the audio processing locally and subsequently send the results (800 byte) or to send raw data packets (32 kB) and do remote processing. For the test setup, the trade-off point lies between 2 and 3 hops, i.e. above 3 hops it is favorable to do local processing. The question, which option is better in terms of energy consumption, remains open.

In general, the network behaved very stable in a test over two hours. Only a small fraction of detections were dropped due to network congestion and network buffer overruns.

4 Conclusion

VoxNet is a custom-made high-level research platform for bioacoustic animal tracking and localization. It exposes an advantage over conventional wired sensor networks with a particular focus on features, speed and high-level programming, but not necessarily energy efficiency. In future, VoxNet shall help to lower the entry barrier for bioacoustic research even further.