12 April 2014**WildSense: Field Tests of a Mobile Sensor Network for Observing Contacts Between Individuals**

Rrf: et al. •

**CAROLINE E. KRUMM,1** *Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, USA*

**N. THOMPSON HOBBS,** *Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, USA*

**JUNHO AHN,** *Department of Computer Science, University of Colorado, Boulder, CO 80309, USA*

**SRAVAN THOKALA,** *Department of Computer Science, University of Colorado, Boulder, CO 80309, USA*

**RICHARD HAN,** *Department of Computer Science, University of Colorado, Boulder, CO 80309, USA*

**SHIVAKANT MISHRA,** *Department of Computer Science, University of Colorado, Boulder, CO 80309, USA*

1 *E-mail: ckrumm@yahoo.com*

**ABSTRACT**

Wildlife telemetry is an important tool for monitoring individuals in a population. Current technology using very high frequency (VHF) radio waves is widely used but cannot accurately measure interactions of individuals. Technology using global position systems (GPS) also has limitations in position accuracy and tend to be expensive. There remains a need for devices that record interactions between individuals and have a measure of distance associated with those interactions. Loss of an individual device in the field can be problematic, resulting in a loss of vital data. Davis et al. (2012) developed a prototype proximity-logging Global Positioning System (GPS) collar that offers greater spatial resolution of social interactions, and reduces probability of data loss. The collar system was tested on captive bighorn sheep (*Ovis canadensis*) and proved to be a robust tool that warranted a field study. In this study we observed free-ranging mule deer (*Odocoileus hemionus* ) nt to test GPS accuracy, contact rates and data logging capabilities of this collar system. We also tested a stationary "listener" node designed to obtain data stored in an individual collar when that collar is in proximity of <30 m and reduce the probability of data loss due to lost study animals or collars. We deployed 6 collars and 14 listener nodes in northern Larimer County, Colorado. The mean GPS fix success rate of the collars was 44.04% (95% CI = 40.77 - 47.31%). The mean percentage of reciprocated communication between collars was 61.06% (95% CI = 57.91 - 64.21%). The duration of interaction ranged from 8-60% within a 24 hour period. Interactions occurred more frequently during the daytime (63.6%) than night (36.4%). None of the listener nodes deployed in the field recorded any interaction data. Further field studies using mark-recapture methods would be useful in evaluating the benefit of listener nodes.

**KEY WORDS** mule deer, data transfer, delay tolerant network, global positioning system telemetry, *Odocoileus hemionus,* proximity logger.

**(Wildlife Society Bulletin 00(0):000–000; 201X)**

The technology available for wildlife tracking has undergone large advances in recent years. Developments focusing on revealing the interactions of animals in a population are increasing wildlife biologists' understanding of population dynamics. Although VHF telemetry systems remain widely used for low-cost wildlife monitoring, the addition of GPS to the collars have added a new degree of precision in wildlife tracking. However, for field population studies, there is still nothing commercially available that allows for the collection of both temporal and spatial data during the study individuals’ encounters and interactions. In this study we evaluated a novel telemetry system called Wildsense with on-board wireless sensor networks (WSN) designed and preliminarily tested by Davis et al. (2012). We deployed the system free-ranging mule deer (*Odocoileus hemionus*) in a remote, rugged landscape.

Commercially available proximity data loggers have shown some success identifying interactions between individuals in field settings (Ji et al. 2005, Prange et al. 2006, Hamede et al. 2009), but are limited by the VHF technology to collect only temporal data (date, time and duration of contact). Improvements in GPS collar technology have greatly increased the accuracy of observations of an individual’s movement. Nonetheless, collecting sufficiently frequent enough fixes to infer interactions or encounters between individuals (which may be brief) greatly decreases the battery life of the collar and therefore the duration of the study, The WSN’s integrated into next-generation GPS collars in WildSense enables the collection of more precise spatial data in addition to temporal and create opportunities for cost-effective population-centered network tracking approaches (Davis et al. 2012).

The delay-tolerant WSN uses a “store-and-forward” message transfer system. The MICAz motes overcome the need for constant connectivity by using components capable of both storing and transferring data (Shah and Kosta 2010). Wildsense ensures that the episodic connectivity between collared individuals are recorded spatially and temporally. This type of data transfer is especially beneficial in rugged and remote field conditions where a continuously connected wireless network is not feasible. Each individual’s data is also exchanged between the collars during these potential interactions. This data redundancy minimizes data loss from damaged or unrecovered collars (Ahn et al. 2013).

Wildsense technology incorporates stationary data collecting nodes in addition to the individual collar nodes (Davis et al. 2013). These “listener” nodes, placed in areas where the study animals frequent, provide an opportunity to download data from the collars from distances <30 m. This could be used as a non-invasive method to collect data regularly, with little field tracking time, from the study animals and ensure data are collected even when a study animal or collar are lost.

We conducted a field study using six wild mule deer captured and collared with the WildSense collars for one month. We were able to evaluate the functioning and data-transfer capabilities of the collars and listening nodes on a herding social animal in their natural, remote and rugged landscape. Of the six collars deployed, five were recovered one was lost. One of the recovered collars contained interaction data from the lost collar.

**STUDY AREA**

We captured deer on winter range in Larimer County,. The majority of the study area was public land, Red Mountain Open Space, a 6000 ha property owned by Larimer County and Soapstone Prairie Natural Area, a 7300 ha property owned by the City of Fort Collins primarily used for human recreation and some livestock grazing. Vegetation is predominantly shortgrass prairie and foothills shrubland characterized by big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridenta*), mountain mahogany (*Cercocarpus montanus*) ranging in elevation from 1800 to 2200 meters.

**METHODS**

**Equipment**

The deer collars were constructed by ATS (Advanced Telemetry Systems, Isanti, MN) with an onboard VHF beacon and a timed drop-off mechanism. cCollar nodes were constructed based on MICAz motes, desirable for their low cost, lightweight, small form factor, RF network and ranging capabilities, software support, and extensibility. We added a GPS module, and operated with Tinyos v1.2.3. The collar node collects GPS-based locations and interaction behavior data via RF radio signals within a 30-meter range and RSSI. A VHF radio was also installed in each collar node, allowing the collar to be located from its VHF beacon within a maximum 8km range. Stationary listener nodes assembled in a waterproof plastic box included a MICAz mote and collect the data recorded on the deer collar when deer wearing the collar come within a 30-meter range from the listener node (Ahn et al. 2013).

We implemented three capabilities to measure deer behavior interaction with our software: interaction behavior data collection, interaction time duration, and level-based distance between sensor nodes on the deer collars. First, each node drops into DTN mode and begins exchanging DTN table data with the other node every 6 seconds when two deer come into close range. The interaction data stored on each collar node includes paired collar-node information such as the two interacting node’s ids, locations, local times, GPS times, RSSI values, and additional table data. Records of the most recent contacts thus propagate further throughout the DTN hop by hop each time there is an encounter between two deer. Second, we log the interaction information on the node’s flash so that we can measure interaction time duration for the paired nodes. Third, we use the radio strength (RSSI) to measure approximate distance between the two interacting deer collar nodes. Although the indicator cannot measure the specific distance between two nodes, the signal strength can be used to calculate the distance within 2 levels of ranges: a 10 meter and a 30 meter range (Ahn et al. 2013).

**Animal Capture**

We deployed collars on 6 free ranging mule deer. Animal capture was in accordance with the Animal Care and Use Protocols of Colorado State University (11-2758A). The deer were captured by helicopter net-gun with Quicksilver Air Company in January 2010. The helicopter transported blindfolded and hobbled deer less than 3 miles to researchers and a veterinarian at the ground processing site. At the processing site we fitted deer with Free Range Sense collars

We released all deer from the processing site.

**Node Deployment**

We deployed 14 listener nodes within the expected home range of captured animals. We assessed areas that deer were likely to congregate or pass by during normal daily or weekly movements. We confirmed the use of these areas using VHF telemetry to approximate the locations of the deer. These locations included water sources, fence lines, and treed areas. We deployed 2 nodes on the most active water tank in the area, one node on a Ponderosa pine tree, and five nodes each on two different fence lines. We installed the last node in the field truck as a mobile unit to cover the study area.

**Collar and Node Retrieval**

We programmed the collars to automatically detach from the deer after three weeks. Once deployed, the VHF beacon on the collar shifted to a mortality signal. We triangulated the mortality signals to locate the collars on the ground. Some of the deer continued carrying the detached collar draped over their necks up to a week after scheduled release. We located five of the six collars during the fourth week after deployment. We never detected a signal from the sixth collar. We removed all of the listener nodes from the field during the same week.

**RESULTS**Wwe assigned IDs from 1 to 6 to the six deer we used in our experiment. Collar nodes collected and stored GPS location data every hour. Deer generally stayed within a 4km2 area. Deer collars that located each other shared data by sending two beacon signals every 5 seconds within 20-second intervals and shared their interaction data every 6 seconds. The mean GPS fix success rate was 44.04% (95% CI = 40.77 - 47.31%). The mean percentage of reciprocated communication was 61.06% (95% CI = 57.91 - 64.21%).

Deer 2 and deer 4 interacted extensively during the experiment period. Interaction data shows that when deer 2 and 4 were located in the same area, they interacted at close range on average 25% of the time per day for the remaining 12 days. The duration of interaction ranged from 8-60% within a 24 hour period, depending on the day. Interactions occurred more frequently during the daytime (63.6%) than night (36.4%). The duration of continuous interaction for deer 2 and 4 was less than 10 minutes for 46% of total interaction time, 10-20 minutes for 21% of total interaction time, 20-30 minutes for 15% of total interaction time, and 40-90 minutes for 8% of total interaction time. The other four deer (deer 1, 3, 5 and 6) interacted only once or twice. We were not able to retrieve deer 5’s collar. However, we were able to collect deer 5 interaction data with deer 2, 3, and 4 by using the DTN algorithm.

We analyzed the possible distance between deer during their interaction using a combination of RF-radio communication data and Radio Strength value (RSSI). Collar nodes recorded RSSI value of the signal whenever deer were within 30 m of each other and exchanged DTN data. If the RSSI value was higher than a 220 threshold strength, the two deer were interacting within a 10 m range. When the RSSI value was measured to be less than 220 strength, the deer were somewhere within the 30 m RF-radio signal range of each other. Using the RSSI value, we calculated proportion of time the deer’s distance proximity was within 10 m as 13.5% and 10-30 m range as 86.45%. **DISCUSSION** Standard collars used by researchers most often track and record the animal locations based on periodic GPS sampling at the rate of once every few hours to conserve battery power, resulting in a scale that is too coarse to capture detailed interaction behavior. Even fixes at the time scale of fractions of an hour will miss many interactions. Our system is designed to capture contact rates at a much finer scale while operating for extended continuous periods of time. The combined use of GPS, proximity-logging devices and delay tolerant networks could aid in understanding fine scale spatial interaction in wildlife populations. This application would especially be useful for documenting individual interactions and how these contacts may play a role in the transmission of a disease. The helicopter capture team confirmed that two of the deer captured were from the same group and the other four were each from different groups . Our interaction analysis confirms that the two deer from the same herd (deer 2 and 4) interacted regularly and frequently with each other. Although they were released from the same location within five minutes of each other, interaction data were not recorded until day 9 post-capture, at which time the deer were within a 30 m range on average 25% of the time per day for the remaining 12 days. Deer 4 collected and stored interaction data of all five other deer which was then shared with deer 2 because of the frequent contact during the duration of the study. The other four deer, captured from different herds, interacted only once or twice with each other. Importantly, we were able to get some location and interaction information of deer 5 even though we never retrieved the collar. Deer 3 and 4 had recorded interaction data with deer 5 in the beginning and the middle of the study period. After that time no further data from deer 5 were collected or recorded. We were able to calculate the possible area in which deer 5 might have been lost as a result of our DTN algorithm for sharing interaction data,. We placed thirteen listener nodes in locations we assumed the deer were likely to travel near at some point during the study. With no prior information on the travel of the study deer, we chose locations that would funnel an animal's movement (i.e. fencelines) or naturally draw animals (i.e. water tanks and trees for cover). None of the 13 listener nodes collected data from collared deer, likely because of the large scale of the study area and relatively few collars and listener nodes deployed. We placed a listener node on the field truck and simulated a recapture method when we retrieved the dropped collars at the end of the study period. With the recapture method, when a collar node is brought near the truck, the GPS tracking and interaction data collected to-date on the collar can be read passively by the listener node without opening the collar and manually downloading the data. In a field study recapture situation this would be beneficial as the deer would quickly be released into the wild again. nsfnsfNSSWhen simulating the recapture method, we found we could collect 200 data points (a maximum of 8 days of GPS information) within 20 minutes. In the future, a mark-recapture study could determine the best locations to place listener nodes. **ACKNOWLEDGMENTS** This research was made possible through funding by the National Science Foundation grants to Colorado State University (Awards 0754606, 0914489) and to the University of Colorado (Award 0754606).

**LITERATURE CITED** Davis, M. J., S Thokala, N. T. Hobbs, M. W. Miller, R. Y. Han, and S. Mishra. 2013. Testing the functionality and contact error of a GPS-based wildlife tracking network. Wildlife Society Bulliten 37:855-861. Davis, M. J., S. Thokala, X. Xing, N. T. Hobbs, D. P. Walsh, R. Y. Han, and S. Mishra. 2012. Developing a data-transfer model for a novel wildlife-tracking network. Wildlife Society Bulletin 36:820–827. Hamede, R. K., J. Bashford, H. McCallum, and M. Jones. 2009. Contact networks in a wild Tasmanian devil (*Sarcophilus harrisii*) population: using social network analysis to reveal seasonal variability in social behaviour and its implications for transmission of devil facial tumour disease. Ecology Letters 12:1147–1157. Ji, W., P. C. L. White, and M. N. Clout. 2005. Contact rates between possums revealed by proximity data loggers. Journal of Applied Ecology 42:595–604. Prange, S., T. Jordan, C. Hunger, and S. D. Gehrt. 2006. New radiocollars for the detection of proximity among individuals. Wildlife Society Bulletin 34:1333–1344. Rutishauser, M., V. Petkov, J. Boice, K. Obraczka, P. Mantey, T. Williams, C. Wilmers. 2011. CARNIVORE: A Disruption-Tolerant System for Studying Wildlife. EURASIP Journal on Wireless Communications and Networking 2011:968046. Shah, H., and Y. P. Kosta. 2010. Evolution or routing techniques, routing protocols, and routing efficiencies for delay tolerant network. International Journal of Computer Applications (Special issue on MANETs):46–53.