# Poster Abstract: SkiScape Sensing

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## 1 Introduction

The bulk of non-academic/experimental wireless sensor network penetration to date has been into areas of environmental and industrial monitoring where people are out of the loop. Recreational sports is a domain where the benefits provided by sensor networks will spark a more general interest in wireless sensor network technology. In this abstract, we present SkiScape, an application for downhill ski resorts focusing on gathering semi-regular trail condition data for immediate feedback to the skier population, and also tracking skier mobility to enable both real-time response, and long-term trace analysis.

Skiers are interested in knowing current trail conditions (e.g., ice, bare spots, congestion) when at the base of the mountain in order to determine which lift to use to get to the desired trail head at the top of the mountain. Resort managers are interested in learning skier flow statistics to estimate wear on the terrain in order to enact preventative maintenance (e.g., close trail, make artificial snow). Safety/emergency personnel are interested in tracking skiers' location and speed in case of accidents (e.g., fall off trail, avalanche), and also to prevent accidents by speed policing. Skiers may be interested in tracking their own location or the location of their friends on the mountain.

We are inspired by the resemblance of a ski resort trail map to a static sensor network data dissemination tree; many trails with heads at the top of the mountain funnel towards a small number of lift entry/collection points at the base of the mountain. In the SkiScape, ski lifts provide a continuous supply of data mules (skiers) to the trails at no cost to the sensing/communication infrastructure. Static sensors, mounted on light poles, sense data about the adjacent trail area; mobile sensors, mounted on skiers, can collect data in their locality as the skier traverses the mountain. Skiers opportunistically collect/carry data of interest as they travel along the trails to the data sinks at the base.

We are deploying SkiScape sensing at the Dartmouth Skiway [2]. With this deployment we aim to demonstrate that a large-scale recreational sensor network is possible and useful. In the rest of the paper we present a description of the SkiScape application, including architectural requirements and the principles of people-centric [1], opportunistic sensing and collection that we employ.


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## 2 Physical Components

In the SkiScape application, the physical deployment consists of Pole Nodes, Skier Nodes, Lift Nodes, and Lodge Nodes. In the following, we give a description of the capabilities, deployment strategy, and sensing roles of each.

Skier Nodes are mote-class devices embedded in rental ski equipment (e.g., ski boot heels) or attached to personal equipment. Skier Nodes are powered with rechargeable batteries and can be recharged on a daily basis (e.g., when rental equipment is returned). Skier Nodes can measure the body area temperature of the skier, collect accelerometer data, and collect short sound samples. The accelerometer data is locally processed in order to measure statistics like maximum G-force on the skier and roughly measure distance travelled. Skier Nodes provide swaths of sensor coverage as they traverse the mountain, and using the radio as a sensor can even detect other skiers off the trail and out of visible range (e.g., Skier Nodes emit a periodic beacon when a boot disconnects from its binding).

Pole Nodes, Lift Nodes and Lodge Nodes are line powered gateways that have a mote-class radio to communicate with Skier Nodes and a backhaul network connection that can be either IEEE 802.11 or Ethernet. Pole Nodes are mounted along each trail of the ski resort, leveraging existing infrastructure currently used for lighting the trail (i.e., poles, line power). Pole Nodes capture trail images via USB webcam, sound samples via microphone, and data from a radar sensor. Algorithms run locally to process the data to identify accidents/injury from the webcam image, the scraping sound of a ski or snowboard edge on ice in the microphone sample, or insufficient snow depth reflected in the radar data. Additionally, temperature data is collected to estimate the rate of melt in the snow pack.

Lift Nodes are co-located with/mounted on lift-related physical infrastructure (e.g., attendant hut) at the base, leveraging existing power infrastructure in place to drive the lifts. Lift Nodes measure the outdoor temperature at the base and also collect and process motor vibration data on the lift machinery for preventative maintenance.

Lodge Nodes are mounted inside the ski lodge and leverage the indoor power infrastructure. Lodge Nodes measure the indoor temperature information that can be fed into the facilities HVAC (heating, ventilation and cooling) system. Additionally, Lodge Nodes can be strategically placed to monitor lodge occupancy statistics.

As an aside, we note that a ski resort has a large altitudinal span, and also has an operations model strongly dependent on the weather (temperature and wind). Thus, the motivation for temperature and temperature gradient sensing is well-founded for this application.

## 3 Opportunistic Data Collection

In the SkiScape application, we leverage a sparse deployment of both static and mobile sensors to give a more complete picture over time of the field of interest at a lower cost than would be required with a fully static deployment. Further, we rely on the mobile nature of Skier Nodes to reduce the cost of sensed data transport to the data sinks. The following briefly describes how data is transported from source to sink using in our opportunistic collection approach [1].

Skier Nodes physically carry locally sensed/processed data about trail conditions to the data sinks encountered along the trail (Pole Nodes) and at the base (Lift and Lodge Nodes). A Skier Node may also mule the data of other Skier Nodes. Selective replication and muling by Skier Nodes may be done to increase the reliability and timeliness of the physical transport of data to the base, e.g., skiers may crash and destroy their motes, snowboarders may spend hours in the terrain park without using a lift. Due to buffer and energy limitations, a Skier Node may have to make decisions about how to adjust local sampling rates, and what locally sensed and muled data to keep in the case of a long inter-rendezvous time with a Pole, Lift or Lodge Node.

Pole, Lift and Lodge Nodes accept all data delivered by Skier Nodes, and communicate this data along with locally sensed data over the backhaul network to a centralized data storage and analysis platform. Pole, Lift and Lodge Nodes advertise their presences using periodic beacons to be detected by passing Skier Nodes. The rendezvous time and data transfer amount between Skiers and Pole, Lift and Lodge Nodes is limited by mobility, and depends on the beaconing rate and also on the Skier Node MAC duty cycle. For Pole Nodes this mobility is at downhill skiing speeds (easily up to 15 m/s), while for Lift and Lodge Nodes this mobility is at human walking speeds (1.3 m/s). We show initial results on the impact of Pole, Lift and Lodge Node beacon power and Skier Node radio duty cycle in Section 5.

## 4 Data Usage

One central focus of SkiScape is to provide data feedback to skiers about trail conditions. After data is transmitted to the centralized data repository it is aggregated and analyzed, and the results redirected to trail conditions signposts to be placed at ski lift entry and exit points to help guide skiers' decisions as to what are the currently desireable trails to ski.

Data in the repository contains metadata concerning originating Node ID, sense time, transfer time, and collection time. The timestamps enable an AutoPatrol feature, where skier speeds can be inferred based on time stamps between Pole rendezvous and citations automatically applied to skiers who violate slow speed zones. Further, skiers may wish to

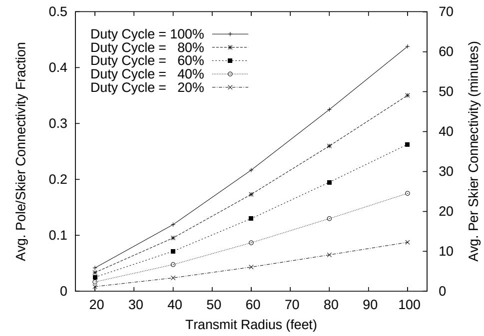


**Figure 1. The left Y-axis shows the fraction of time skiers on trails are connected to Pole Nodes. The right Y-axis shows the corresponding average per-skier total connectivity time in the 8 hours of simulation time.**

prove to their friends that they did the double black diamond slope, or to find out where on the mountain their friends are (FriendFinder feature) to know whether to go up the lift (they are waiting at the top) or go to the cafeteria (they went in without you), or they are half way down (wait at the lift).

## 5 Initial Results and Future Work

We have implemented a simulator that captures several mobility features particular to ski resorts and uses a simple disk radio propagation model to estimate connectivity between Skier Nodes and Pole, Lift and Lodge Nodes. Skiers move on a trail by choosing a random downhill destination that remains within the coordinate constraints of the given trail. Progress toward the destination is updated in accordance with the skier's speed at each tick of a master clock. A skier's speed and fall probability are functions of the skier skill and trail difficulty. At a trail end, a skier chooses randomly from available next locations for the given trail (e.g., linking trail, lift). Currently, intra-lift and intra-lodge movement is abstracted with a fixed "dwell time". Figure 1 shows Skier/Pole Node connectivity over a range of transmission distances and radio duty cycles to give an idea of the amount of data the could be transferred between the two using a fairly realistic skier mobility model. The actual lift and trail layout of the Dartmouth Skiway [2] is used and Pole Node placement is at random along the trail edges with average 300ft spacing. Lift dwell times are based on actual lift speeds. The results are for 300 skiers over an 8 hour period.

SkiScape represents the first proposed large-scale ski resort wireless sensing deployment of its kind in the literature, and provides an opportunity to bring wireless sensor networking into human recreational activities, an item of general societal interest. In addition to the work described here, we have designed an architecture [1] whose software and hardware components support the requirements of SkiScape sensing. We are rolling out the required physical infrastrucure at the Dartmouth Skiway [2] over the next year and will report our experiences to the community.

## 6 References


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[2] Dartmouth Skiway. http://www.dartmouth.edu/ skiway.