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Street CORNERS: Architecture for Correlation of Networked Environmental Sensors

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Abstract – *Wireless sensor networks can provide a wide range of information, gathered from both active and passive sensing. In urban environments, using an example application of environmental sensing on street corners, the benefit of active sensing, which includes monitoring and reporting of real-time data, such as calculation of passing traffic rate and measuring noise, can be easily seen. Passive information gathered from urban sensing might include sampling the air quality along a roadway for detection of road and urban pollutants. A network architecture has been developed to integrate active and passive sensor information gathered from urban environmental sensing networks. Depending on the active sensing information gathered, passive sensing information may be gathered, for integration with active sensing, and escalation for alert reporting. Using the selected illustration application of a wireless urban environmental sensor network, the correlation of information gathered in near real-time is presented and discussed.*

Keywords: *wireless sensor networks, urban sensing.*

I. INTRODUCTION

Currently, wireless sensors are used to monitor a number of environmental factors, such as tremors associated with earthquakes and beach erosion, as well as the status of animal habitats [1]. Civil infrastructures, such as bridges and roads, are also monitored by wireless sensors [2]. However, the use of wireless sensors for real-time monitoring and data correlation for the urban environment has not occurred. One barrier to success was cost, as well as deployment and retrieval challenges. As costs have fallen, near real-time monitoring in an urban environment, such as street corners, has become more feasible. Previous surveys using mobile sensors [3] have monitored only one environmental factor and have not done so in near real-time.

Two types of monitoring or sensing are discussed here. *Active* monitoring refers to information gathered on demand, or in response to an external trigger. Active monitoring information is usually calculated in some form, as is it relative to the last reported value. *Passive* monitoring, in contrast, is ongoing, and has threshold values, which when exceeded, result in a trigger for an active monitoring measurement. The gathering of passive data, and if appropriate, of active data, permits data correlation which can indicate if an environmentally hazardous condition exists or some other condition for which prevention steps should be taken.

II. URBAN SENSING NETWORKS

Sensor networks have been considered for a variety of applications [4]. The low-cost, low-power, and multifunctional aspects of sensor nodes permit them to be deployed in a wide range of areas. Here, we consider an urban network environment such as that found on a street corner.

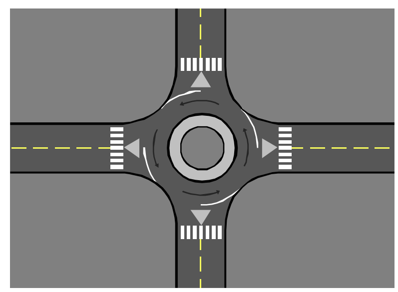

Figure 1. Traffic circle and street corners suitable for active and passive sensor installation.

A. Active and Passive Environmental Monitoring

Active sensor information refers to *dynamically* calculated information, such as traffic rate or volume increase. Passive sensor information refers to *statically* measured information, such as temperature, humidity, or other atmospheric measures. In the event that an active sensor report merits further understanding, an assessment of the passive sensor report might be necessary. For example, if an active sensor detects an increase in traffic rate or noise level, atmospheric sampling by a passive sensor network node may illustrate that pollutants are present and preventive action should be taken to reduce the number of cars and trucks directed to this intersection. Alternatively, the passive sensor network node might indicate nothing extraordinary, and a follow-up active sensor measurement may support this, as the traffic rate and/or noise level would have returned to normal levels.

If desired, passive environmental monitoring could be done independently of the more active monitoring, but in the presence of chronic conditions, such as those found in urban areas, passive monitoring correlated with active monitoring might provide information in advance of traffic build-up, or environmental spill with fumes, for example.

B. Wireless Sensor Network Design and Implementation

The Street Corners network, where ‘corners’ is a concatenation of letters from the phrase “*Cor*relation of *N*etworked *E*nvi*r*onmental *S*ensors” is composed of wireless sensor nodes. Our initial network includes light, humidity, barometric pressure, and seismic sensors, and includes a network gateway. The Street Corners network is deployed on the Kean University campus, which is located at the crossroads of several urban communities, making it ideally situated for urban environmental data collection and analysis.

Figure 2. The IRIS 2.4 GHz Mote module used in the Street Corners implementation.

Our implementation uses sensors from Crossbow Technology, Inc., such as the one in Figure 2, and includes IEEE 805.15.4/Zigbee compliant processors. The initial implementation is a preliminary framework, which will be modified over time to include a greater variety of sensors, as the information to be correlated increases, along with our understanding of the best locations for collection of accurate environmental sensing data. Manufacturer specifications state that this mode is suitable for large scale sensor networks, composed of 1000 or more. Our initial efforts include sixteen sensors, two base station nodes, and a sensor network gateway, suitable for connecting the sensor nodes to our existing campus Ethernet. A representative illustration is in Figure 3.

The wireless sensor nodes are located in environmental monitoring spots on campus. While actual street corner implementations are ideal, additional spots such as rooftops and radio towers are also outstanding, depending on the environmental data to be gathered. The sensor nodes can be easily moved and the network reconfigured.

A continuing challenge is the durability of the wireless sensor nodes. Most nodes are designed for protected or “indoor” use. We use our nodes outdoors, but avoid extreme weather conditions. Ideally, as wireless sensors become studier and more ‘weather-worthy’, longer-term outside environmental observations will be possible.

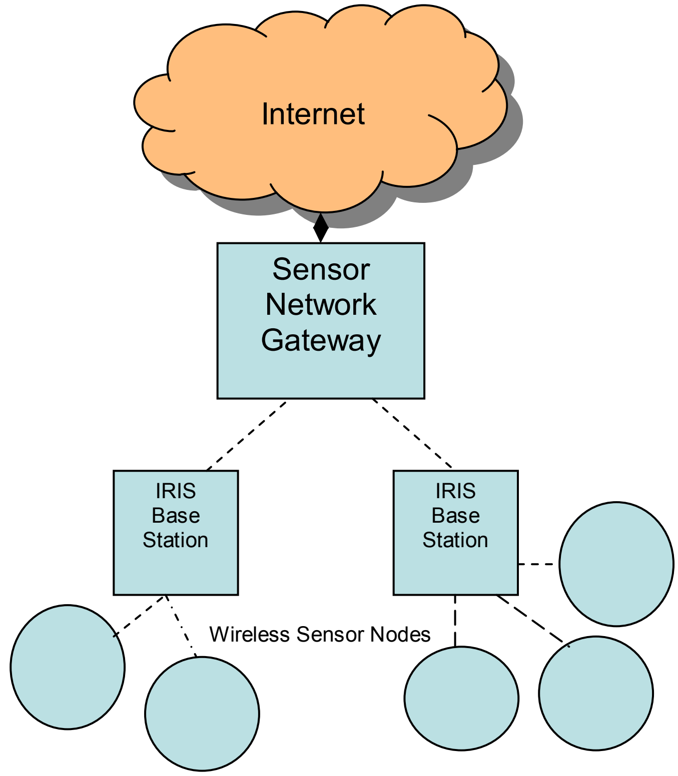

Figure 3. Street Corners Network Design

C. Wireless Network Application Integration

Current research efforts are addressing the integration of the active and passive monitoring environments. Several earlier efforts have addressed the active monitoring environment [5], but not to the level used here. Additionally, the integration of environmental information factor is unique. Earlier work on network management agents [6] is applicable here, including monitoring, integrating passive data (environmental monitoring) and active data (traffic and audio monitoring), filtering and forwarding, for review and archiving.

The need for information-sharing in an architecture for wireless sensor networks has been recognized [7]. Our focus is on the variable set which the sensor can monitor.

When considering the urban sensing network, the network topology can be regarded both as a horizontal slice and vertical, as depicted in Figures 4 and 5.

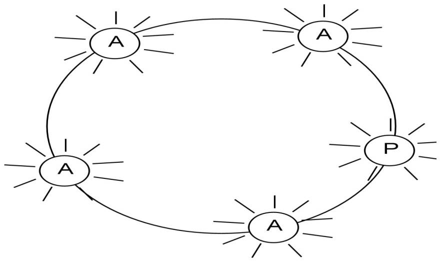

Figure 4**.** Horizontal view: A functional depiction of an urban sensing network, such as might be found on a street corner or intersection. Several active sensors (A) could interact with one passive sensor (P).

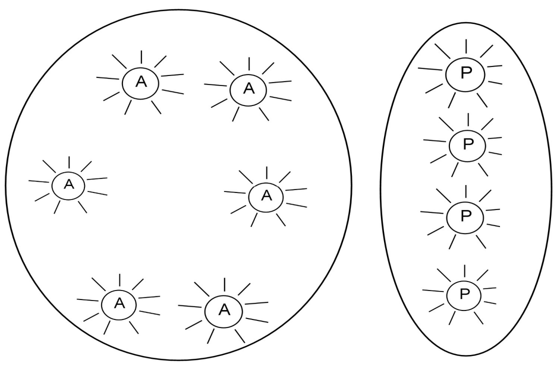

Figure 5. Vertical view: A functional depiction of an urban sensing network along a multi-story apartment or office building. Numerous active sensors (A) *throughout* the height of the space could interact with passive sensors (P) found closer to ground level.

Early efforts to develop a wireless sensor network, composed of nodes designated as either 'active' or 'passive' has been positive. From a modeling perspective, active nodes and passive nodes differ only in the sampling rates assigned to them and the feature sets available to each. The advantages of a physical two-tier network architecture [2] map to a logical two tier architecture with the same benefits. The passive sampling environment is a low data rate, low transmission range subsystem, while the active sampling second tier is capable of a higher data rate with a larger transmission range, as needed for escalation.

D. Wireless Sensor Node Sampling

Active wireless sensor network nodes sample data more frequently and are capable of performing calculations to determine if the data just gathered is significant. This is done by comparison with either a benchmark value shared by another network node, to be used for comparison, or historical values retained for comparison. Due to the resource constraints of wireless sensor network node architecture, very little information is stored locally, except as needed, and this information can be refreshed or updated as needed, if network conditions or alarm thresholds change.

Passive wireless sensor nodes sample data less frequently, and generally do a time-comparison, looking for extreme deviations from an earlier sample, most often 24 hours earlier. The previous sample is rarely of immediate interest, as passive sensor nodes are most often used to track changes over 24-hour time periods.

The urban environmental wireless sensor network topology considered here is that of an urban traffic intersection. For example, if one concern was air quality on the exterior of a building, passive sensor network nodes could be places in appropriate locations, including street corners. Additionally, if the concern was further expressed that large truck traffic through the area, which could be measured by the vibrations to the sidewalk and roadway, was extremely heavy at times, this could be determined by measuring the vibrations experienced by the sidewalk and roadway surrounding the residential apartment building, and correlating this, by timestamp or other mechanism with passive environmental samples taken during the same timeframe. This would permit review and counting of the number of large trucks, and a correlation with air quality during the time when the trucks were passing. This would quantitatively determine if there was a correlation between air quality and large truck traffic near the residential apartment building.

Environmental Feature	**Parameters Sampled**
Air Quality	CO_2, CO, traffic volume
Transport Contaminants	Wind speed, direction

Table 1. Environmental feature assessed, with sampling parameters

As illustrated in Table 1, the parameters sampled can vary according to the environmental feature being measured.

III. URBAN SENSING NETWORK ARCHITECTURE

Predictive uses of wireless sensor networks for urban environment networks are expected to provide the most benefit. An architecture to support information sensing, and then, through integration of data gathered, provide an escalation point, is illustrated in Figure 6.

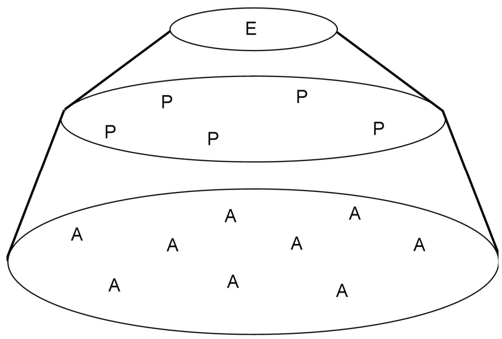

Figure 6. A lower tier of active sensors (A) gathers the information, and if appropriate, passes the details on to the passive sensors (P), found in tier 2. Tier 3 holds the escalation (E) environment.

Previous work in sensor networking information architecture [8] identified the use of clusters and a clustering hierarchy as being useful in support of scalable operations. This is most certainly needed in an urban sensor network architecture. While previous work has considered the use of a cluster head to perform information filtering, the architecture proposed here has all active sensors on equal footing, with peer capabilities. This provides potentially superior network management, as all active sensors can forward to passive sensors. All passive sensors are enabled to escalate information received as needed. The peer network architecture provides improved performance, as resources are not consumed with hierarchical network functions.

As was identified in [8], information gathered from sensor networks is ideally not node-specific, but rather area specific. This data-centric approach, where information about an area or region of interest is gathered, rather than a specific sensor, is ideal for active and passive sensor information integration.

Significant challenges in deploying the selected sensor equipment in the architecture envisioned included determining the best sensor location. The location selection was determined by several factors. The two primary features were the validity of the data which would be collected from each sensor location and the ability of the sensor to withstand environmental extremes. Fortunately, wireless sensor nodes are lightweight and portable, which permits a poor location choice or extreme weather concerns to be addressed quickly with immediate wireless sensor relocation.

IV. ESCALATION

Each active sensor can sample specific attributes. When a selected attribute falls outside the desired range, passive sensing information can be requested. The integration of the active and passive sensing information composes a pair of data points. If the passive sensing attribute sampled falls outside a desired range, escalation to an external site may be required. A sequence which might be used for this activity is depicted in Figure 7.

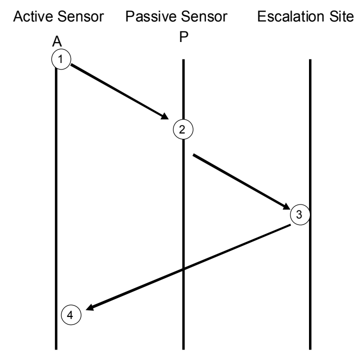

Figure 7. Escalation sequence involving Active and Passive sensors, with an Escalation Site.

The steps in the sequence depicted in Figure 5 are as follows:

1. An active sensor measures an attribute value. If the value is outside a previously specified Value_Threshold_Range, then a request is sent to P.

2. A Passive sensor measures another attribute value. If this value is outside a previously specified Value_Threshold_Range, then

3. Escalation takes place, with the gathered data pair from (A, P) sensing being forwarded to an Escalation site or node.

4. If further information is needed, a response will flow from the Escalation site or node directly back to the Active sensor, or perhaps the Passive sensor, depending on needs.

Interaction in the proposed urban sensor network architecture can take the form outlined in Figure 8.

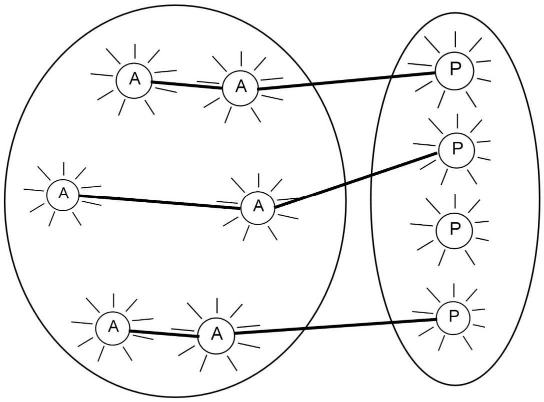

Figure 8. Possible communication scenarios between active and passive sensor nodes in the urban sensing network architecture.

An alternative understanding of the escalation from a local active sensor through passive sensing and escalation to higher level network awareness is possible as outlined in Figure 9. Network management is also accomplished via this hierarchy.

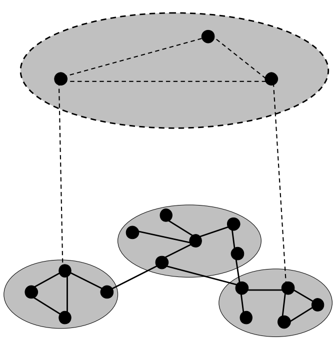

Figure 9. Depiction of an active sensing network (bottom, center) with communication to potentially two passively sensing networks (bottom, left and right). Escalation from the passive sensing networks is depicted by the escalation site (top network).

For example, using the environmental features listed in Table 1, transport contaminants might be the environmental aspect of concern. If contaminants are detected through passive sensing, wind speed and direction would be actively calculated through escalation, and if the contaminants were biologically or chemically harmful, further escalation would be warranted.

In addition to correlating the data gathered for environmental understanding, the use of static information, such as location, time, and date, to provide contextual meaning to the information is being tagged with the sensing information, to provide a larger dataset for data mining and environmental pattern detection.

V. FUTURE WORK

As outlined here, the urban sensing network proposed provides a low-cost approach to an application such as environmental monitoring, which might require the monitoring of chronic conditions over time. Motivated by the application, a first-tier sensor measurement, by passive sensors, is complemented by a second-tier measurement by active sensors. Information which might be measured would include dynamically-calculated information (active sensing), such as traffic rate, followed by statically measured information (passive sensing), such as temperature or other environmental assessments, including air quality.

While keeping in mind the low-power and limited processing capabilities of the wireless sensor networks, previous work has shown that this type of architecture is possible [7, 8] and needed [9]. The contributions of this paper are:

1. The integration of actively and passively gathered information, using the proposed urban sensing network architecture.

2. The illustration of how this architecture might be deployed for environment monitoring.

3. An outline of the sequence of steps which an escalation scenario might follow in the event information gathered at local sensing sites was significant.

Further work on this topic includes augmentation of the proposed architecture to filter out possible false positive sensor measurements, which might erroneously indicate escalation, and design of a mechanism to dynamically change the Value_Threshold_Ranges specified, whether over the course of a day, or due to changing personal needs.

Future efforts include interfaces to the active and passive sensing data which will permit visual presentation of the information gathered. Predictive algorithm design, suitable for trend forecasting, is also underway.

The urban sensing network architecture outlined here holds significant promise for urban communities. The anticipated benefits are great, as the resulting system is expected to be easy to use, low cost, and reliable.

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