Cooperative sensing in distributed military environment using smart devices

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Abstract:
The distributed environment of a military theater can be represented by an aggregate model and be measured by a set of scattered sensors on mobile devices. The state of this system can be reconstructed, and displayed to each device. The architecture of the proposed system is fully distributes since no central controller is used. Android operation system is investigated using Wi-Fi Direct (WD) technology installed in common smart devices. These devices collect measurements using embedded sensors. It is assumed that the average of the measurements is the output of a military controlled process. The proposed methodology consists of a two steps approach. The smart devices exchange messages according to the proposed average consensus protocol. In the second step an adoption of Kalman filtering in each device and the estimated states are presented as graphs on the smart device using a suitable application.

Key-Words: - Distributed systems, distributed Kalman filtering, military sensing systems, smart devices.

1. Introduction

Smart devices have become popular, easy to use and continuously even less costly. They provide a variety of sensors that take measurements of the local environment and exchange messages to the neighbour devices using suitable protocols [1]. United States Department of Defense has a dedicated agency for the use of new technologies in the military, Defense Advanced Research Projects Agency (DARPA), which states that program Transformative applications or apps "*are built around the idea that every soldier will carry a military certified Smartphone in the near future*" [2]. Android is an open source operating system for these devices enabling the development of a wide range of applications [3]. It has a variety of sensor control libraries which can be used to measure environmental signs. Android distributions contain built-in libraries to let the app read data from sensors which enables us to use the mobile as a custom device. The existing sensors on a commercial Android device are mostly low cost solutions result the problem of a more accurate measurement of environmental variables [4]. To take accurate and precise measurements for military purposes stronger high end micro sensors may be needed. Energy and mobility are considerable parameters in mobile and ad-hoc networks.

2. Android environment

A solution to the problem of sensor accuracy is given by developing frameworks to enable an Android device to communicate with external sensors. To let a smart device communicate with sensors other than the pre-installed, a two-style framework solution can be proposed. The first is to develop application-side software [4] and let a commercial Android device communicate with a microcontroller in which sensors could be installed, as shown in Fig. 1. In this solution, the communication can be implemented via Wi-Fi or Bluetooth from the Android enabled smart device. The second way is to install Android OS on a Linux enabled microcontroller like Beaglebone or Arduino [4], see Fig. 2, and fully customize the interface in which it will be used on. In that case the microcontroller should have a Wi-Fi or Bluetooth antenna. Most Android devices have Wi-Fi and Bluetooth technology. On the contrary microcontrollers usually do not have any of those or just have Bluetooth, but they can be connected on USB Wi-Fi and Bluetooth extensions.

3. Communication algorithms

3.1 Conventional Wi-Fi

The most popular ways to connect two or more Android devices is via Wi-Fi or Bluetooth. Both technologies can be used on Ad-hoc networking, but the energy efficiency is not the same on both [4], as shown from measurements of throughput in terms of energy efficiency of Wi-Fi and Bluetooth using TCP/UDP transfer protocols for Wi-Fi and RFCOMM for Bluetooth. The experiments were conducted in multiple scenarios resulting that Wi-Fi is much more energy efficient related to its throughput.

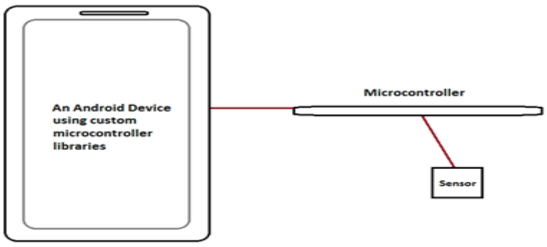

Fig. 1: Android device with external sensor.

The Wi-Fi technology has many routing algorithms for ad-hoc networking. The Ad-hoc philosophy reflects the uncertainty of the position of your neighbour, that is the reason that most wireless sensor network routing protocols come with a link quality estimator [5], Collection Tree Protocol [6] (CTP), Beacon Vector Routing protocol [7] (BVR) and Burst Link Aware Routing [8] (BLAR) are protocols that use estimators to suggest link - paths for routing.

BLAR was tested [8] to have a more robust behaviour in a crowded environment. Having obstacles and moving objects could cause some nodes to have a bursty behaviour and could probably cause congestion or in general a lower routing performance. The BLAR algorithm consists of two parts [8].

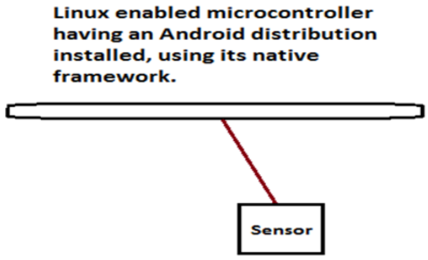

Fig. 2: Controller-side architecture using advanced sensors.

The first part consists of a Burstiness Identification Method (BIM) that keeps track of the receive signal strength indication. In the second part and if it identifies that the suggested link is going to have a bursty behaviour then it informs the adaptive link quality estimator, named EasiLQE, which will observe the subject link more frequently and decide whether to change route.

3.2 Wi-Fi Direct

Wi-Fi Direct (WD) is an emerging technology that allows peer to peer (P2P) connections between wireless nodes without the need of an intermediate access point [9]. WD offers the ease of immediate communication between devices that are Wi-Fi Certified and support the IEEE 802.11 standards but as [9] states, the IEEE 802.11b-only devices have compatibility problems mostly because IEEE 802.11g is the newer replacement of 802.11b (11Mbps) and most Wi-Fi enabled devices support the 802.11g (56 Mbps) standard.

Comparing WD and Ad-hoc networking

The philosophy of WD is very similar to Ad-hoc networking but with some important differences. Wi-Fi Direct networks support WPA2 encryption contradicting Ad-hoc networks that mostly support WEP which is a previous generation security protocol [9]. Another important feature of WD is that it can connect directly to other existing networks as well as better handling of node discovery. In general the main differences between Ad-Hoc networks and Wi-Fi Direct networks are:

- Security: WPA2 vs. WEP
- Throughput: Wi-Fi up to 200 Mbps + vs. Zigbee (mostly used on Ad-hoc) up to 250kbit

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- Range: Wi-Fi Indoors up to 20 meters, outdoors 20+ meters (varies on antenna) vs. Zigbee 10 to 100 meters.

In [9] a clear overview of the Wi-Fi Direct technology and the procedure that WD follows in order to form a group of devices are given.

The standard procedure for the creation of a WD network group consists of 4 stages (Fig. 3):

1. Discovery
2. GO (Group Owner) Negotiation
3. WPS Establishment
4. Address configuration

On the Discovery phase the devices are searching for nearby devices that are WD compatible. On the Group Owner Negotiation the devices 'decide' which will be the Group Owner or the access point. The WPS (Wireless protected setup) phase is a security concerning activity in which an extensive exchange of EAP (Extensible Authentication Protocol) messages takes place exchanging network credentials to securely pair the devices. On the final stage (Address Configuration) using the Dynamic Host Configuration Protocol (DHCP) the mobile nodes are assigned IP addresses.

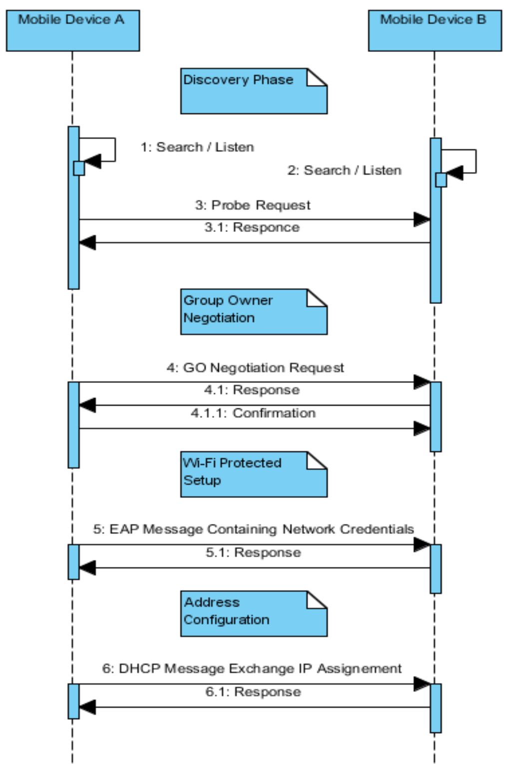

Fig. 3. UML Sequence Diagram of the Wi-Fi Direct Procedure.

4. Problem Formulation

Each node collects local measurements, exchange these with neighbours and converge to a global estimate.

The problem is to model the process of target tracking in a military environment using the environmental variables from a server-less distributed network of Android devices that have a burst aware routing protocol like BLAR.

The architecture is a fully distributed computational resource scheme and will be designed to be optimised for state estimation.

5. Problem Solution

5.1 Kalman filtering

The aggregate model of the system is given by the equation

$$x(k+1) = Ax(k) + w(k) \quad (1)$$

$$y(k) = Cx(k) \quad (2)$$

where x, y, w are the state, output of the system and uncontrolled noise inserted to the system. Also A, C are known system parameters.

The system is considered to be linear and the noise Gaussian.

Kalman algorithm predicts the next state of the system $S([k+1|\square]_k)$ based on the known model. This is called a priori state estimate. Then, the filter uses the measurement of system output and updates the state estimate to $S([k+1|\square]_{k+1})$, which is called a posteriori state estimate [10-11].

Considering an arbitrary guess of the initial value of x(k) the a priori state estimation of the system is given by

$$\tilde{x}(k+1) = A\hat{x}(k). \quad (3)$$

After using the measurement of the output of the system z(k) the estimated state can be re-evaluated as

$$\hat{x}(k) = \tilde{x}(k) + k\big(z(k) - C\tilde{x}(k)\big). \quad (4)$$

This is called a posteriori state estimation, where K is a suitable defined gain which can be optimally determined using Kalman theory [10, 12].

The Kalman-Bucy filter is an optimization of the original filter, usually referred as optimal Luenberger observer [10].

In a central system the output of the system is the measurement of the installed sensor. In this case the sensors are distributed and their average value is the output of the system.

Average consensus protocol is used to obtain the average of the measurements

. (5)

5.2 Average consensus

Let a set on n smart devices. These devices communicate with a direct wifi protocol and form a not fully connected network as depicted in Fig. 3.
The Laplacian matrix of the undirected graph is defined as [13-14]

$$L = \begin{cases} 0 & \text{if } i \neq j \text{ not connected} \\ -1 & \text{if } i \neq j \text{ connected} \\ -\sum_{i=1}^{n} L_{ij} & \text{if } i = j \end{cases} \quad .(6)$$

The average consensus protocol is defined by

$$z_i(k+1) = (I - aL)z_i(k) \quad (7)$$

where I is the identity matrix and a a suitable scalar parameter.
This protocol is proved to converge to [13]

$$z_i(\infty) = \frac{1}{n}\sum_{i=1}^{n} z_i(0) \quad (8)$$

which means that each sensor will display the average value of all.
The value of the convergence will be at every device where the Kalman filter runs independently and the state estimation is calculated.

6. Illustrative example

A system is simulated in the Malbal environment to illustrate the proposed methodology.
The system constists of 5 devices/sensors and is shown in Fig. 4.

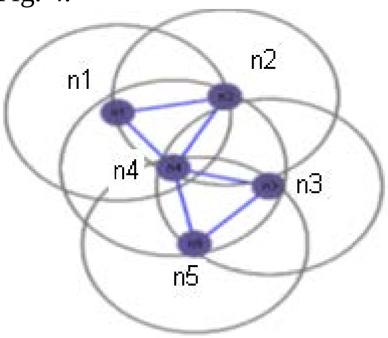

Fig. 4. The graph of the 5 sensors used in this example.

The resulting Laplacian matrix of the network is

$$L = \begin{bmatrix} 2 & -1 & 0 & -1 & 0 \\ -1 & 2 & 0 & -1 & 0 \\ 0 & 0 & 2 & -1 & -1 \\ -1 & -1 & -1 & 4 & -1 \\ 0 & 0 & -1 & -1 & 2 \end{bmatrix}. \quad (9)$$

The response of the system is drawn in Fig. 5 and in Fig. 6. the average consensus is icluded in the graph. Fig. 7 displays a detail of Fig. 6 where the consensus protocol is clear.

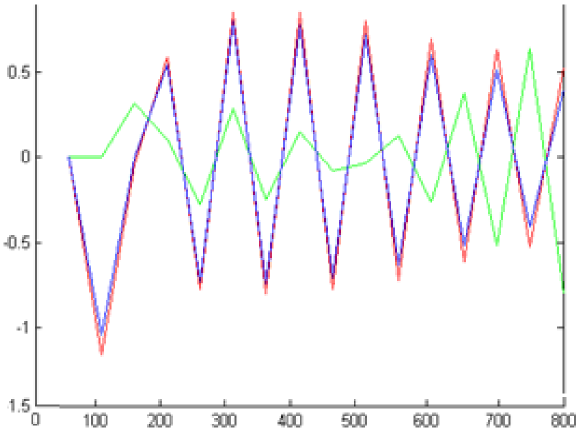

Fig. 5. Response of real system (red).
A priori estimation (green).
A posteriori estimation (blue).

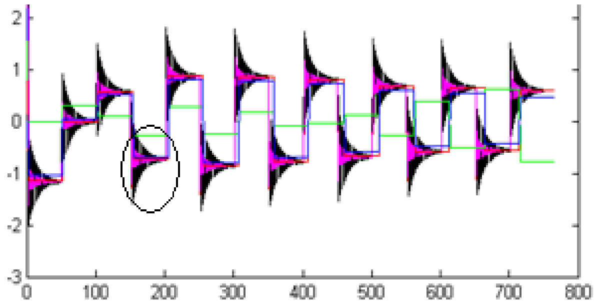

Fig. 6. Average consensus and system estimation. The detail in the cycle is depicted in Fig. 7.

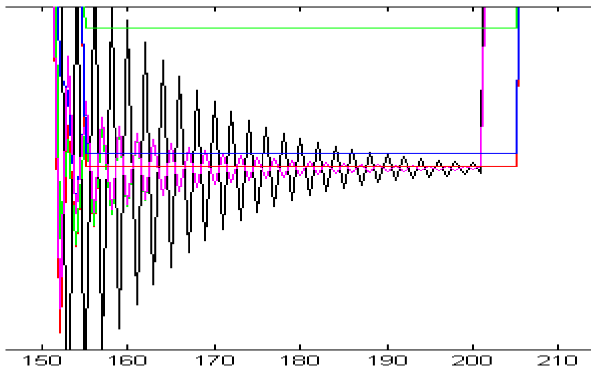

Fig. 7. The detail of Fig. 6. The average consesus of the 4th measument is presented.

The display of the proposed android application is presented in Fig. 8.

Fig. 8. Typical display of the android application. The displayed labels were chosen arbitrarily.

7. Conclusion

The android development environment was used to design a distributed application in a military theatre. The sensors of smart devices and a two-step data fusion algorithm were used to reconstruct the distributed state of a military process.

The first step is an average consensus algorithm and the second a Kalman filter removing noise from measurements.

The proposed system has been successfully simulated giving satisfactory results. The whole system is expected to be implemented, tested in real scenarios and tuned with suitable control laws.

Further work will cover issues on security and energy saving

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