Quality of Information and Efficient Delivery in Military Sensor Networks

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Abstract: Sensor networks represent a powerful new data paradigm facilitating the development of new intelligent applications. A sensor networks utility can be measured by the quality of information (QoI) that it provides for these applications. This paper focuses on the concept of QoI and a technique enabling efficient delivery of information to other parts of the sensor network, to facilitate decision making.

1. Introduction

With the introduction of autonomous, battery operated, wireless communication capable sensing platforms, multi-modal sensor based systems are becoming very powerful and flexible sources of data that support a wide collection of applications. Sensor networks are often deployed over an area of interest to gather information to aid some form of decision making, in support of these applications, such as surveillance. The area of interest, from where information is required however, can be considered tedious, dangerous, expensive or sometimes impossible to collect.

Successful conduct of a mission in a military context depends very much in part on the commander and subordinates being supplied sufficiently high quality of information (QoI), from sensor networks that meet specific information requirements. QoI is therefore a characterisation of the goodness of the data captured by and flowing through the sensor network, for example location and identity of any personnel or equipment to sufficient resolution within a specified geographic area and time frame. The research challenge therefore is to design a sensor network, with protocols, that can meet a specific information requirement with sufficient quality in the context of a specific mission, whilst satisfying user requirements such as operational longevity.

The quality of information that a sensor network delivers depends not only on the capabilities of the sensor. Information processing algorithms used to transform raw sensor data to information at the desired level of abstraction, sensor deployment topology, environmental parameters (e.g. atmospheric conditions) and the behaviour of the event being sensed are also key parameters [4].

In this paper we present a formal hierarchical model in order to compute the QoI of a sensor based system deployed in different scenarios. We present and consider quality factors such as accuracy, certainty and timeliness, to provide confidence in the information provided by the sensor system. We then highlight our technique that can facilitate delivery of high and needed quality of information to other designated parts of the sensor network within a disruptive communication environment.

2. QoI Problem Formulation

We consider a multiple multi-modal sensor based system deployed into a location. We describe the problem of determining the QoI as follows:

1. Let **S** be a sensor based system designed for providing a set of information items (e.g. sensed events) $\mathbf{I}^r = (I_1, I_2, \ldots, I_r)$, r being the total number of information items. The sensor system S utilises a set of $L^n = (L_1, L_2, \ldots, L_n)$ of $n \geq 1$ number of media streams obtained from heterogeneous sensors.
2. Let $q_{b,j}$ ($1 \leq b \leq k$, $1 \leq j \leq r$) represent the b^{th} quality factor for the j^{th} information item and k being the number of quality factors used. Let q_b be the quality factor contributing towards the overall QoI value at the system level **S**.

Our objective firstly is to compute the quality Q_j, $1 \leq j \leq r$ for all the individual information items and secondly the overall QoI of the system **S**. This is illustrated in figure 1.

2.1 Quality Factors

For the purpose of illustration, the model presented in figure 1 is based on three quality factors (k=3). These are accuracy (q_1), certainty (q_2) and timeliness (q_3).

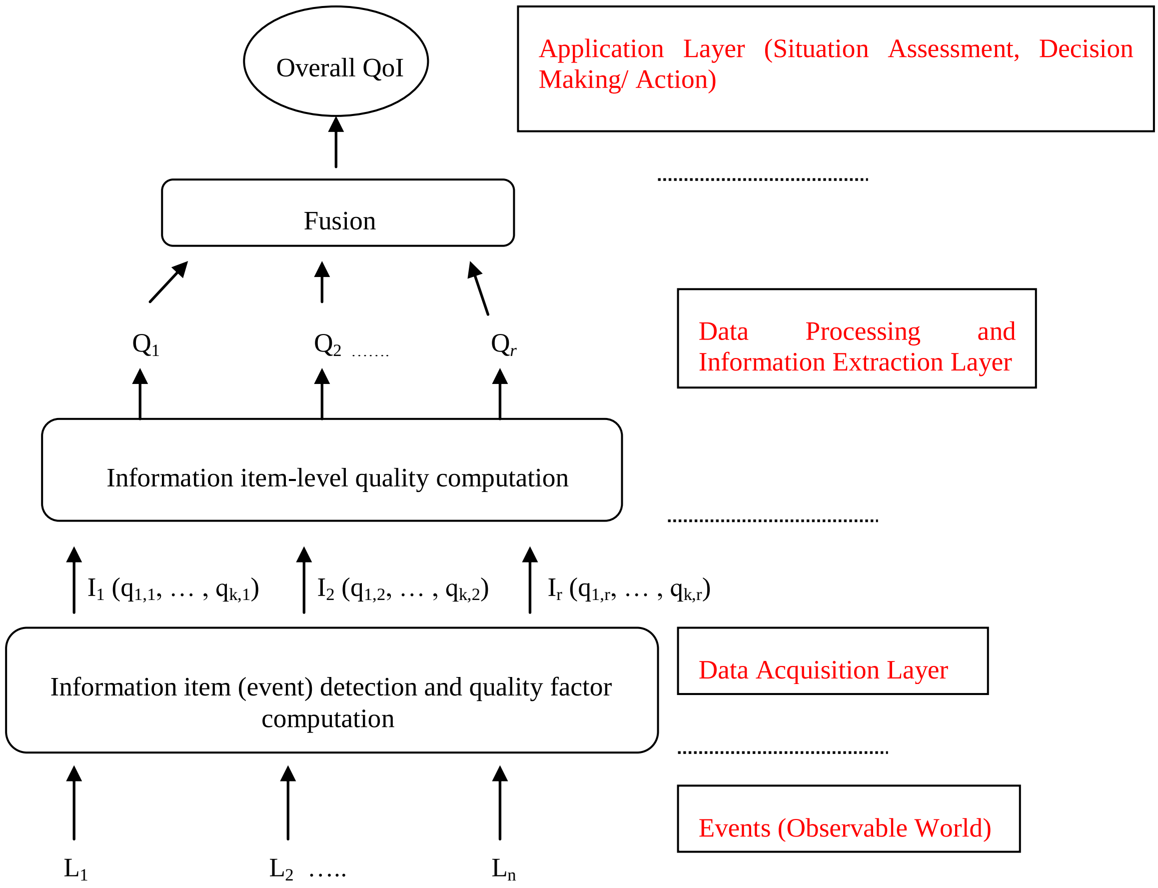

Figure 1: QoI Computation Hierarchy for Sensor Enabled Mission Specific Systems

2.1.1 Accuracy

Accuracy refers to the degree of how the observed information conforms to reality, within a certain specified time frame. The accuracy of event detection is the ratio of the number of correctly detected events to the total number of events that occurred in the environment. The accuracy $q_{1,j}$ for the j^{th} information item level is computed as:

$$q_{1,j} = E_{C,j} / E_{T,j} \quad \textit{where } E_{C,j} \textit{ is the number of correct detected instances of jth event} \tag{1}$$

$$E_{T,j} \textit{ is the total number of instances of jth event}$$

2.1.2 Certainty

Certainty represents the measurement of confirmation of the information, in the form of a probability score. The score represents the confirmation level of the identified events, within an uncertain environment, given by the following equation:

$$q_{2,j} = Avg\left(Prob(I_j \mid L^n)\right) \tag{2}$$

$Prob(I_j \mid L^n)$ represents the probability of existence of the information item I_j (e.g. occurrence of an event) based on the set L^n of n media streams. *Avg* is a function to average the certainty level of an individual information item over a period of time.

2.1.3 Timeliness

Timeliness is a measure of information being available at the desired time and the ability to link related events that occur at different times (i.e. Building a coherent picture over time). The system is expected to detect the j^{th} information item (event) within time T of its occurrence. However, if the system takes time T + Δ, Δ being the delay, then the timeliness is measured as:

$$q_{3,j} = {}^{T}/_{T\, +\, \Delta} \tag{3}$$

2.2 Overall QoI computation

For each information item I_j ($1 \leq j \leq r$), the quality factors $q_{b,j}$ ($1 \leq b \leq k$, $1 \leq j \leq r$) are computed according to the formalisms described above. These factors are combined to calculate the quality of information at individual item levels (Q_j, $1 \leq j \leq r$) as follows:

$$Q_j = \sum_{b=1}^{k} w_b \times q_{b,j} \tag{4}$$

In equation 4, w_b is the weight of the b^{th} quality factor, with a value between 0 and 1 and signifies the relative importance given to the quality factor that has more significance to the current mission context. Usually a linear weighted sum fusion strategy as in [1] is adopted, by assigning normalised weight to different quality factors. The sum of all the values of w_b ($\sum_{b=1}^{k} w_b$) is equal to 1. The overall QoI value for the sensor system **S** is the summation of all the quality values Q_1 to Q_r of the individual information items:

$$QoI = \sum_{j=1}^{r} Q_j \tag{5}$$

3. Deriving QoI Measures from Mission Specifications

Mission specifications can be considered as information requirements that are questions about the physical world at some level of abstraction over a given time window, typically limited to a specific geographic region. In this paper we do not consider arbitrary questions expressed in formal query language, but rather pre-defined, parameterised information requirements. For illustrative purposes this could mean "*Detect Gunfire in this area, over this timescale with high Certainty and Accuracy*".

From a sensor network perspective, information is delivered as event reports, each of which has meaning and value to support a higher level view of operational environment. For example a sensor network detecting gun fire issues a report whenever it detects a shot. Relating this to the above mission specification, this could mean "*Probability of a gunshot in the designated area in the past second is P_d*". Specifying a specific P_d value in the overall mission specification can assist the sensor system in delivering the required QoI requirement back to the command centre or other designated parts of the network, for assessment.

4. GAFO: For Reliable Delivery of QoI to Support Mission Needs

This section describes some our previous work carried out in supporting transmission reliability within a disruptive environment [2] [3], this being communicating within a varying channel environment. Within a static multi-hop WSN, varying channel conditions (sensor mobility) can make the existing point-to-point route invalid before another route must be chosen. The loss of nodes to link instability can cause significant topological changes and reorganization of the network.

Communicating to forward data within varying channel conditions therefore has implications for throughput and energy efficiency since:

- Data packets not received (lost) have to be retransmitted, increasing node energy consumption. In sensor based systems memory and processing are relatively cheap but energy is not. Storing sensed data and performing information processing, to minimise redundant data and forwarding this when routes become available is a sensible option. Data Bundling can be incorporated to allow different data packets to be combined together in order to conserve energy, in communicating.

- Retransmissions limit useful data being sent and so decreases overall network throughput.

GAFO [3] has the ability to make adaptive informed decisions within this scenario on next hop node selection for QoI forwarding. By applying a genetic adaptive fuzzy hop selection scheme (GAFO) for QoI/data forwarding, using both signal to noise ratio (SNR) and outage probability (Pout) as input parameters, offers improved transmission reliability performance, as shown in figure 2. In figure 2 for comparison purposes, FLS represents the non-adaptive fuzzy logic hop selection and crisp being the direct values received from the channel. Figure 3 shows the overall block diagram structure of our GAFO algorithm.

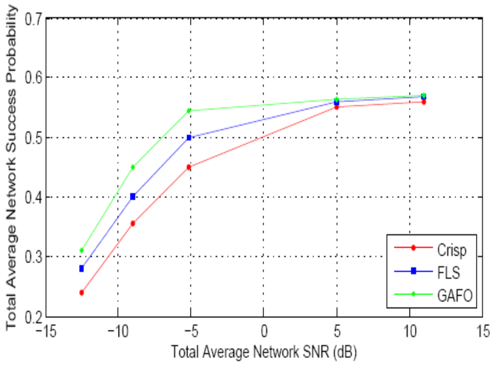

Figure 2: GAFO Total Average Network Success Probability

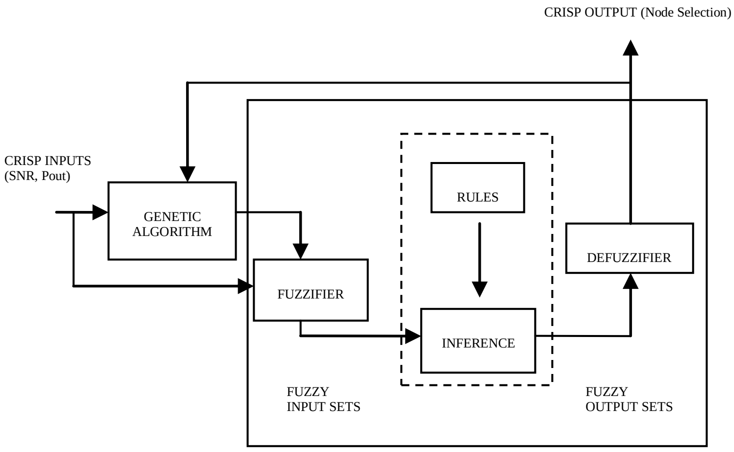

Figure 3: GAFO Algorithm Structure

5. Content Based Routing for Efficient QoI Distribution

Conventional routing schemes require the sender to know a destination address before it is able to transmit information. Content based routing (CBR) is an advanced form of multicast, allowing receivers to partake in an interest group, to which a sender may direct information. CBR is a publish/subscribe mechanism, where a node declares predicates that it is interested in. Messages are key/value pairs, which are checked against this predicate. An example is:

```
[Class="Gunfire", accuracy=6, device type="acoustic", alert-
type="Intrusion"]
```

This would match a predicate of interest such as:

```
[(alert-type="intrusion" & accuracy > 2) | (class="alert" & device-
type="Infrared")]
```

CBR provides routing based on logical predicates, and it operates by using a control protocol to distribute routing information, and a separate data routing protocol, to distribute information to interested parties.

6. Conclusions

This paper proposes a generic model for evaluating the quality of information (QoI) delivered by a sensor system. Evaluating such quality is important in a military context since it may provide increased confidence and trust in the deployed sensor system, for intelligence, surveillance and reconnaissance (ISR) information. Applications that reside depend on high QoI to make “decisions” and take corresponding actions. Delivering this information to other parts of the network for the basis of “decision” making requires a reliable and efficient mechanism. This paper also highlights a potential method to able this within a disruptive communication channel environment.

Acknowledgments

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