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A Critical Study Of Existing Approaches Based On Quality Of Information Attributes And Metrics In Wireless Sensor Network

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ABSTRACT

In Wireless Sensor Networks (WSNs) the working conditions and/or user requirements are often desired to be evolvable, whether motivated by changes of the monitored parameters or WSN properties of configuration, structure, communication capabilities, node density, and energy among many others. This paper targets the current research activities that attempt to address Quality of Information (QoI) in a manner which provides the groundwork for the design, deployment and operation of WSNs. To build a common considerate and overcome the ambiguity in different existing definitions, we provide a generic definition of QoI and briefly summarize the existing approaches declaring the building blocks they are focused and what the effects of neglecting other blocks are. We provide an analysis of the design features, solutions, pros and cons that have been adopted by current QoI frameworks and methods. We mainly propose and argue for a holistic view for QoI, and quantify the QoI as the user evolvable requirements may be not satisfied while processing the data/information from the source to the sink.

Indexing terms/Keywords

Wireless sensor networks, Quality of Information, metrics, Qualitative;

TYPE (METHOD/APPROACH)

Literary Analysis; Survey/Interview

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1. INTRODUCTION

Wireless Sensor Networks (WSNs) are a distributed collection of sensor nodes having potential in domains such as monitoring, automation, health-care etc. The core functionality of WSNs is (a) to generate the minimal required raw data, (b) to process this data in-network in order to extract the appropriate information specified by the user, and (c) to deliver the information to the user. It is worth mentioning to distinguish the terms data and information. Data refers to basic monitored facts/chunks (e.g., sensor readings) and information is the collated and interpreted data systematized by purposeful acumen and processing required for an application (e.g., event occurrence). There exist a few classifications on information, which are unfortunately specific to certain WSN functionalities. Therefore, we present a comprehensive classification of WSN information in this paper.

In WSNs, the various applications and users drive the specific information needs. The user requirements regarding information are evolvable having specified information with a certain quality. Also the achievable information quality is evolvable according to the operating conditions such as network and environmental conditions. Accordingly, the WSN functional operations should be designed while considering the fluctuating operating conditions and the user's evolvable requirements on information quality. We refer to quality as the degree or grade of excellence, and to Quality of Information (QoI) as the quality experienced/perceived by the user concerning the received information, which (may) fully accomplish the user evolvable requirements while saving valuable resources such as energy and bandwidth.

Similar to Quality of Service (QoS) in traditional networks, QoI is significant in WSNs and considered as the center of attraction for users, designers, decision makers, application planners etc. There exists no survey detailing the attributes/metrics/techniques related to QoI. We take the opportunity to review the snapshot of the state-the-art of this emerging research field, and to discuss the pros and cons of the different existing QoI approaches

2. STRUCTURAL DESIGN AND SYSTEM MODEL

Usually, in WSNs the raw data collected undergoes in-network processing and then transported to the sink for decision making. To define decision making let's first define decision, meaning a selection between alternatives. Decision making is a choice between one or more paths of action. One important factor in data processing operations is sensor data/decision fusion [1]..

The value fusion is the operation where raw data from different local nodes are fused, i.e., filtered, aggregated, etc. The decision fusion is the operation where the local decisions from many sensor nodes are fused [2] [3]. The sensor nodes completing the fusion are known as fusion centers. Usually, fusion centers fuse local decisions from n sensor nodes into one user relevant decision for detecting a certain event. We assume a feedback channel to transport information back to sensor nodes as show in Figure 1. Feedback channel is also used for user requirements dissemination. We refer to the different operations on raw data and then on the constructed information by the building blocks of the WSN

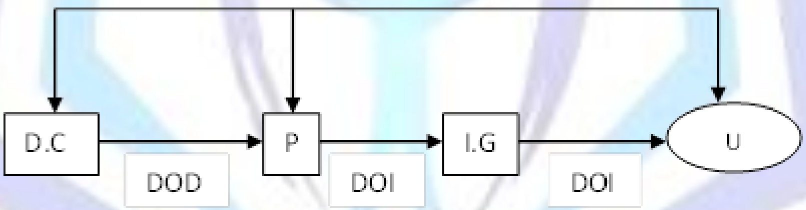

Figure 1: WSN Functional and Communication Channels

P -- Processing DOD – Direction of Data flow

U -- User DOI – Direction of Information

D.C – Data collection (Raw)

I.G -- Information Gathering

3. INFORMATION CLASSIFICATION

The existing classifications of information in literature [4] [5] are more specific towards information transport and service level. For example, the classification in [4] is concentrating on reliable information transport itself, and not on the other building blocks. However, we require a classification of information which is general in order to suit to the holistic QoI approach, i.e., considering all the building blocks.

Information is usually present in different forms depending on the user evolvable requirements. For example there might be different user's pertaining to obtain information from the same event of interest. However, the information can be different depending on the requirements such as perimeter, wind, temperature, humidity etc. Without loss of generality, we identify three classification criteria's for common types of information that a WSN can deliver: Usage time of data (Criteria 1 or C1), type of the information (Criteria 1 or C2), and construction location of the information (Criteria 3 or C3). In Table I, we summarize all the resulting classes.

3.1 Prediction Information [C1-P]:

Refers to the information that can be forecasted before its occurrence.

Examples are predicted important events such as, user events and forecasted network partitioning [6].

3.2 Real-Time Information [C1-R]:

Is the information which is created just after (during) the occurrence of event. It is required that this information reach the sink/user with a best effort latency.

3.3 Historic Information [C1-H]:

Refers to the information that is of interest after their occurrence/creation. It is usually stored at the sink. Examples of applications that require such information are forensics, statistics etc.

3.4 Query Result Information [C2-Q]:

This information is the result of a user query to the deployed network. Example is the average temperature in a certain region of the network.

3.5 Event Information [C2-E]:

Is a set of attributes of an event of interest that occurred in the sensor field. Examples are: the type, time and location of the detected event.

Information classification	**Types of classification**
Criteria 1: Usage time of Information [C1]	Prediction Information [P] Real-Time Information [R] Historic Information [H]
Criteria 2: Type of the Information [C2]	Query Result Information [Q] Event Information [E]
Criteria 3: Construction location of the Information [C3]	Information Constructed In-Network [N] Information Constructed at the Sink [S]

Table I: Information Classifications

From the above generalized classification, almost all the building blocks, characteristics, applications and services fit into one of the categories. However, the first classification is the future perspective class. Whereas, the second classification is well established and know. On the other hand, we are more interested in the construction of information, because of its relation to the in-network processing, information creation, information transport and sink operations. Therefore, we further classify it. Without loss of generality, in WSNs information is created from raw data either:

3.5.1 Information Constructed In-Network [C3-N]:

The information is created within the network.

3.5.2 Information Constructed at the Sink [C3-S]:

The information is created at the sink

We know further sub classify the classification according to Criteria 3 as follows:

Information constructed in-network on a centralized sensor node. The centralized node has received/processed the necessary raw data or local decisions from different sensor nodes.

Information constructed at the sink with a few distributed sensor nodes which are local and non-continuous. The raw data is sent to the sink from a few sensor nodes from the region of event of interest.

Information constructed at the sink with a distribution on all sensor nodes which are global and continuous. The raw data is sent to the sink from all the sensor nodes and the information is created at the sink. Example, to construct the information about the perimeter of the region of deployed WSN.

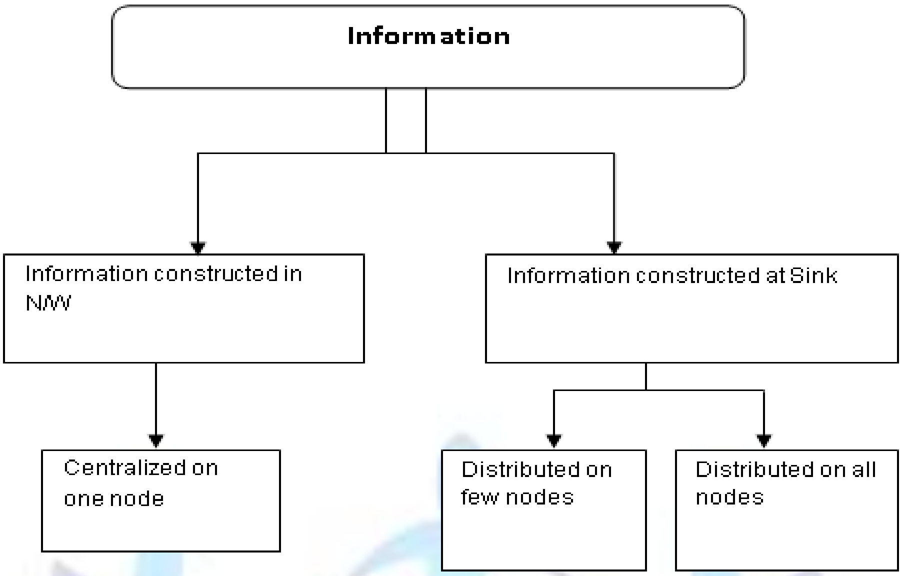

Figure 2: The Adopted Classification of Information

4. INFORMATION CHARACTERISTIC

4.1 Quality Dimensions

Information quality as such, unfortunately, is difficult to observe, capture or measure. Information quality dimensions are the means by which we can measure quality of Information [27]. Several researchers have identified the dimensions of information quality with as many as 15 dimensions identified by Strong et al. in 2002. In another research project, a literature review was conducted to find out the list of most common information quality dimensions [29]. In that study, papers dealing with all quality dimensions and published during the years 1996-2005 were examined and the frequency of each dimension was calculated across those publications.

4.2 Timeliness

Timeliness is the degree to which information is up-to-date. It can be seen in an objective fashion, meaning that information represents the current state of the real world. Timeliness can also be seen as task-dependent, meaning that the information is timely enough to be used for a specific task. It is one of the most important quality dimensions for handling disasters, because providing new information instantly is a major success factor of preventing a disaster or mitigating its effect. Information must be timely, and not “stale”. Stale information is what has become outdated and has been replaced by new information. The implications of untimely/stale information during a disaster can be considerable. Not only does it lead to the expending of valuable time in processing that information, but it also prevents the appropriate response needed by the actual situation. To enable coordination and synchronization of multiple operations, information has to be up to date. Quoting an e-mail sent by a White House Homeland Security

Council officer during the Katrina response:

“… sending us very stale sit rep info that has already been updated (earlier) by the HSOC is not as helpful. Is there a way to coordinate the info flow so we don’t waste time receiving such old data and you folks don’t waste time sending us stuff?” [28]. Also, Timeliness and Accuracy go hand in hand. When a situation changes dynamically, any situational information that is not timely is not accurate.

4.3 Security

Security has been identified as another important information quality dimension. If information is not secure, it can be easily intercepted by any intelligent opponent (e.g., terrorists, criminals) and used in a harmful manner. For example, if there is a huge fire that needs to draw police, medical and fire responders from surrounding areas, and if a criminal comes to know this, (s)he can take undue advantage of this information: (S)He can identify which area lacks police force and commit a crime in that area. This information quality dimension is especially important when there exists an active and strategic opponent (e.g., in a terrorist attack situation), as the degree of damage that can be done by information leakage in such cases can be extremely higher. Two aspects of information security include protecting information from intentional and unintentional human acts (information security) and protecting information from disasters (disaster recovery planning). Cyber security relies on logical barriers such as data encryption, passwords and transaction authentication, along with human vigilance. Disaster recovery planning involves protecting information and ensuring appropriate back-up and alternate processing procedures are in place [27].

4.4 Accessibility

For information to be utilized in an effective manner, it must be accessible. Accessibility implies the degree to which information is available, easily obtainable or quickly retrievable when needed. But this availability of information to the users is generally within the constraints of policy and confidentiality. Knowledge of the existence of information, its availability, and the tools necessary to acquire it are key attributes of access [30].. It enables information sharing, giving an impression as if resources were centralized. When coupled with timeliness, it permits synchronization of interdependent activities. Accessibility is an important issue in a disaster situation as it often happens that all means of communication get disrupted in a disaster.

For example, during Hurricane Katrina, the communication infrastructure was completely devastated in many parts of the affected area, and the responders had very tough time in coordinating their emergency response operations [32]. It got to the point that people were literally writing messages on paper, putting them in bottles and dropping them from helicopters to other people on the ground." [33]. The disaster management organizations should identify the technical and other barriers limiting the access to information during disasters and make a cooperative effort to surmount them.

4.5 Completeness

Completeness is the degree to which information is not missing. Incomplete information can be hazardous. However, complete information for one person may be incomplete for another. For example, emergency medical services, FBI and Fire crew, all may be interested in the weather conditions around the disaster site, but each may require different levels of detail. Just as information of which precision exceeds a recipient's processing capability may be too accurate, information may also be too complete. During a disaster, it's also an adverse situation that the amount of information generated is so much that processing it all in a timely fashion becomes infeasible. At the same time, in a disaster response, if information is incomplete, it becomes difficult for the responders to accurately assess the situation and hence they are unable to respond effectively. The following excerpt illustrates this situation:

"…..Each data set was examined to evaluate the completeness of records as a useful indicator of quality. The mere recording of the occurrence of a disaster with no other information on it makes the record essentially unusable for analyses [31]."

4.6 Accuracy

Accuracy is the degree of correctness and precision with which information in an automated system represents states of the real world. It is a very important quality dimension that on which many early information quality studies have focused. Within information production processes inside organizations, accuracy can be improved by implementing institutional procedures, like having information double checked by two independent people, or by installing technical means, like calibrating sensors or verifying shipping address information received through a website against an address database. The concept of accuracy implies the assumption that information can be captured in an objective fashion. Thus, accuracy is not applicable to subjective information, like destructive impact, public perception or political views. Inaccurate information may be worse than no information at all. Example, if a fire crew does not know the type and extent of situation at a disaster site, they will at least try to extract more information. However, if they have been given inaccurate information, they may respond with inappropriate strategy, which may lead to loss of innocent lives. Similarly, inaccurate information about the death toll in a disaster can lead to pandemonium in public.

4.7 Coherence

Coherent information is what "gels" or blends with itself consistently. Incoherent information can lead to confusion and panic during a disaster. This can lead to wastage of valuable time as well as resources. Coherence implies that two or more values do not conflict with each other. Information generated during a disaster is likely to be inconsistent as multiple information providers, which might use different procedures to capture information, have different levels of knowledge and different views of the world. Since most people are exposed to information through a number of media and from various sources, it must be consistent in order to be credible. Inconsistent information tends to confuse people and allows them to discount some or all of it. For example: " numerous organizations--state agencies, the Red Cross, school authorities, and media outlets--in California met in the immediate aftermath of the Loma Prieta quake just to discuss and agree upon the wording all of them would use for the "Drop, Cover, and Hold!" message ."

4.8 Relevance

Relevancy is the extent to which information is applicable and helpful for the task at hand.

Information must be relevant as per the demands of situation, i.e., it must address the needs of the end user to whom it is being transmitted. For example, when a user calls a 911 operator to tell about an emergency, he might tell irrelevant details out of panic. The operator must analyze what information should be sent across to the responders and ask relevant questions to complete the information. The key component for information quality is whether the information addresses its user's needs. If not, then the user will find the information inadequate regardless of how well the information rates along other dimensions mentioned in this chapter.

4.9 Validity

Information should be valid in the sense that it must be true and verified; it must satisfy the set standards related to other dimensions such as accuracy, timeliness, completeness and security.

The most common form of information validation is auditing. Auditing can uncover mistakes and is a good way to measure the quality of information[33]. Validity is a resultant rather than a causal dimension of information quality. This means that even though some information may be classified as being highly 'valid', it still may fall under poor quality information if other crucial dimensions like accuracy, timeliness etc. is absent [27].

"…..When indicators possess high degree of reliability and validity, the data and information they generate is more useful in continuously improving performance. Conversely, indicators that are unreliable and invalid produce confusing, irrelevant and useless data and information while consuming precious resources.….."[34]

4.10 Format

Information must be in such a format that it is uncomplicated and easily understood by the end user. This is especially true in a disaster situation as minimum time must be wasted between information processing and actual response. Information format refers to how the information is presented to the user. Two key components of information format are its underlying form and its context for interpretation, which is sometimes referred to as its frame[27]. The appropriate format for information depends on the information's recipient and the information's use. For example, while giving demographic details or statistics of any past event, multi-color pie charts may be a better format than putting numbers. Moreover, during disaster management, if there is a commonly agreed upon format for exchange of information between two organizations, say Fire department and 911 operators, it aids understandability and expedites the response. Since here might be huge data to handle, it's always better to keep them formatted instead of letting them go haywire. "For each disaster, too many database and software have been developed and designed and millions of money has been expended. These projects are substantially costly and the main problem are the existing of many parallel sub-systems and activities and repeat labor works in different database format which have to be created for each hazard management systems. Such methodology will be so complicated due to implementation of different platform, different database format, and different program languages and so on. This will make all projects costly and non-efficient." [35]

5. INFORMATION QUALITY ASSESSMENT

Usually, the quality of delivered/achieved information should be assessed according to the required/expected quality. For a quantitative assessment, metrics play a major role. In the following, we briefly discuss the user requirements on QoI as well as the QoI metrics.

5.1 User Requirements:

As mentioned before, QoI is complied with a set of attributes. These attributes are measured by relevant metrics to give the level of detail of QoI. Hence, we consider that user requirements are information based on some set of attributes. The user requirements can be further regarded as measured information based on a specific set of attributes. User is not necessarily a human and can be application planner, end user, decision maker, consumer, intelligent system etc. The use of feedback channel is important here for user requirements dissemination.

5.2 QoI Metrics:

Measuring the information quality is quantifying the information attributes. Metrics are valuable at both design and deployment time as the user requirements are evolvable and the user would benefit from knowing the level of QoI of received information entities for safer decision making. Measuring an information attribute is either completed in-network or/and at the sink. A metric is a standard of measurement stated in quantitative term which captures the performance in relative to standard on the occurrence of event. The quality of a system, such as its energy-efficiency, information attributes such as accuracy, timeliness etc. and the evaluation criterion of these qualities are judged by the term metric. Measure can be classified as "happening" and "valuing". For example of fire detection in the forest, there is fire is the true state of event happening, there is fire with 95% accuracy is the valuing of the event. If the metric is well defined it has to lead to actionable performance to satisfy the deployed system and also needs a capable system model to measure it. This doesn't mean to have high rate of data collection or reliable protocol or having non-effective metrics satisfy the user evolvable requirements. Hence, we can define that a metric is acceptable with certain performance measure only if it has some opening limit, meaning it is a limit which is likely near/above to threshold value or real world value. There are quite a few metrics defined in the literature such as probability of error [7], Peak Signal Noise Ratio (PSNR) [8], recall and false-positive rate [9], path weakness [10], transient information level [11] etc., but not for all the attributes mentioned above such as tunability and affordability. However, these metrics are not the sole to measure other attributes such as accuracy, precision and reliability.

6. QUALITATIVE COMPARISON OF EXISTING APPROACHES BASED ON QOI ATTRIBUTES AND METRICS

This sub-section is the classification of QoI approaches based on attributes and metrics, which are used to characterize and quantify QoI. We always argue that to have achievable QoI pertaining to user evolvable requirements, user needs to respect the characteristics of QoI. Moreover, we present some of the approaches concentrating only on some attributes and measuring them.

The principle based framework [12] is a strategy of principles and steps to achieve ideology of deployment planning, decision making, and quality enhancement. The current state of art on layered framework for decomposing the deployment evaluation is done in three steps of input processing, core analysis and result post-processing. The framework uses probability of error to measure detection probability and false alarm rate. The main aspect of detection in WSNs is any event, in [23] detection performance is measured with average sampling rate with characteristics such as accuracy and timeliness.

The QoI aware route control in [7] uses probability of error as metric to measure accuracy. It explicitly optimizes application relevant QoI metrics during network resource allocation decision. The QoI approach presented in [8] focuses on accuracy and measure it with Peak Signal Noise Ratio (PSNR).

However, though the QoI here is measured, other attributes such as timeliness for timely arrival of information for decision making have been not discussed. Exploiting the tolerance for characterization of information quality using fuzzy logic [1] some attributes such as accuracy, completeness, relevance, timeliness and usability are explored. However, though the work considers some attributes relevant for QoI, never quantifies it. In QoI with characterization of information, Information Risk Management (IRM) [21] is also proposed in the literature to minimize the risks such as information misunderstanding and insufficiencies of metric which may affect learning quality. Dimension extension (DIME) is a framework to accommodate local and prior knowledge into learning coarse by measuring accuracy through dot product as metric. To achieve better results, data processing is used in current trends of QoI. Usually, in resource constrained framework a real good data processing is a key precondition for analysis decision and data integration. One of the frameworks [19] addressing this is based on rule base, scheduling and log management. The attributes such as consistency, accuracy, extensibility and interactivity are used for data cleaning and measured by metrics such as recall and false-positive rate. The overall design fully shows the features of extensibility and interactivity, meaning the framework allows users to add rules, and at the same time allows user to form strategies in the needs of different data cleaning. The concept of operational context to ease the dynamic binding of sensor resources to applications represents QoI needs of an application and the capabilities of the sensor resources by the 5WH (why,12 where, when, what, who, how) principle [25]. With the interpretation of the 5WH primitives provided, spatial and temporal relevance is used as a metric to measure data completeness. The evolution of the context may be used to adjust dynamically the weights of the sensor nodes that ease selecting the right set of sensor nodes given the dynamic context change as the one in [16]. Some attributes such as certainty, accuracy/confidence and timeliness are used for context aware QoI computation. Still here the information is not measured. Relative to this the selection of sensors can be made by using metrics such as information gain and using other attributes missing in [16]. By targeting all the building blocks and attributes related to each block, we now brief a strategy [10] that develops a game-theoretic metric called path weakness to measure the qualitative performance of different routing mechanisms. The approach uses qualitative performance as a QoI characteristic and uses sensor-centric concept. Considering information transport, prioritizing traffic has been studied for a long time. Disregarding the fusion process and not focusing on the sensor fusion aspects, if those processes have been completed, the framework as in [11] handles the QoI assigned message in the network. Based on this the key metric transient information level is defined, which is the product of information and projected physical distance of that information from destination node. This approach is very relevant to QoI information transport block as attribute related to information transport such as timeliness of information are used. The QoI level is also measured, but the approach neglects the effects of other building blocks and some attributes.

Approaches	**Building Blocks**	**Attributes**	**Metrics**
QoI Analysis [12]	[C2C], [D,I]	Detection probability and false positive rate	Probability of error
QoI in DTN [11]	C1S], [T]	Timeliness, integrity and consistency	Transient information level
QoI Computation [16]	[C2C], [D,S]	Certainty, accuracy, timeliness, integrity	NA
Characterization of Information Quality [1]	[C1S], [S]	Accuracy, completeness, relevance, timeliness, usability	NA
QoI Rate Control for Sensor Networks [7]	[C2C], [D,I]	Accuracy	Probability of error
Information Fusion [14]	[C2C], [I,S]	Uncertainty	NA
Data Model Framework [13]	[C2C], [D,I]	Accuracy, reliability	NA
Resource Management [17]	[C1S], [D]	Completeness, uncertainty, accuracy	NA
Data Driven Sensor Reporting [18]	[C1S], [D]	NA	NA
QoI Management [19]	[C2C], [D,I]	Certainty, completeness, accuracy	Entropy

QoI Inspired Analysis for WSN Deployment [20]	[C2C], [D,I]	Accuracy	Probability of detection and false positive rate
QoI an Empirical Approach [8]	[C1S], [D, I, S]	Accuracy	Peak Signal to Noise Ratio
Information Risk Minimization [21]	[C1S], [I]	Accuracy	Dot product
Sensor Sampling and QoI [22]	[C2C], [D,I]	Accuracy, timeliness and confidence	NA
Detection Performance [25]	[C2C], [D,I]	Accuracy, timeliness and robustness	Average sampling rate
Data Cleaning [9]	[C2C], [I, S]	Consistency, accuracy, extensibility, interactivity	Recall and False-Positive Error
Quality of Routing [10]	[C1S], [T]	Qualitative performance	Path weakness
Information Awareness [26]	[C2C], [I, S]	Precision, quality and usability	**NA**
Dynamic Target Tracking [24]	[C1S], [S]	Accuracy, timeliness	Entropy, information gain, residual likelihood
Letter Soup for QoI [25]	[C1S], [D, I, S]	Accuracy, completeness, timeliness	Spatial and temporal relevancy

Table IV: Classification of QoI Approaches Based on Building blocks, attributes and metrics 13

7. CONCLUSION

Though information attributes are relatively well discussed, QoI metrics definition and their efficient computation are still in their infancy. Accordingly, the future research directions may progress on the aspects of defining metrics and the techniques to efficiently compute them on the fly in all information extraction stages. However, as one need to narrow research into fewer attributes, one will take some must considered attributes during the flow of information from the source to the sink. One can define and defend how it is relevant and necessary to use these attributes and violation of this lead to QoI which does not satisfy the user requirements. Akaike's information criterion, is a measure of the goodness of fit of an estimated statistical model grounded on the concept of entropy, in effect offering a relative measure of the information lost when a given model is used to describe reality. As an example, Akaike's information criterion can be used to measure QoI when certain information is lost from the source to the sink. Metrics and their run-time quantification represent a powerful tool to assess the dependability of WSN, which allows for efficient and tunable QoI provisioning.

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