Quality-of-Service in Underwater Acoustic Sensor Networks

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***Abstract*— Underwater Acoustic sensor networks (UW-ASNs) are one of today's most prominent instantiations of the ubiquitous computing paradigm. In order to achieve high levels of integration, UW-ASNs need to be conceived considering requirements beyond the mere system's functionality. While Quality-of-Service (QoS) is traditionally associated with bit/data rate, network throughput, message delay and bit/packet error rate, we believe that this concept is too strict, in the sense that these properties alone do not reflect the overall quality-of service provided to the user/application. Other non-functional properties such as Scalability, Timeliness, Energy-Sustainability, Reliability, Mobility, Security must also be considered in the system design. This paper identifies the most important non-functional properties that affect the overall quality of the service provided to the users, outlining their relevance, state-of-the-art and future research directions.**

Keywords— ***Underwater Acoustic Sensor Networks, Quality-of-Service, Non-Functional Properties, Scalability, Timeliness, Energy-Sustainability, Reliability, Mobility, Security.***

I. INTRODUCTION

In this paper, we focus on the most relevant properties of UW-ASNs that, although not affecting their functionality, but affect their performance or behavior. These are the so called Non Functional Properties (NFP) and include scalability, reliability, robustness, timeliness, security or energy. By employing a broader (than the traditional one) view of Quality-of-Service (QoS), we refer to them as QoS properties.

QoS has been traditionally defined as a set of traffic characteristics for a network service. These characteristics may include performance-oriented as well as non-performance-oriented criteria. The non-performance-oriented group defines the parameters priority, cost, and level of service. These do not directly affect performance of communications, but are concerned with related matters. Traditional QoS criteria provide a view of service parameters that is very independent and are thus limited in the way they reflect the *overall* QoS provided to the user/application.

We believe that UW-ASN calls for a broader perspective of QoS. Each UW-ASN application/task (which can be rather diverse [5]) must be correct, secure, produced "on time" and with the smallest energy consumption possible. UW-ASNs are expected to be highly heterogeneous besides being cost-effective, maintainable and scalable. They must also be as much "invisible" to their users/environment as possible, to be seamlessly accepted and used at large scale. Therefore, QoS should be seen at and addressed in a more extensive and holistic perspective, instantiated in a wider range of properties, namely heterogeneity, energy-sustainability, timeliness, scalability, reliability, mobility, security, cost-effectiveness and invisibility.

II. DESCRIPTION AND RELEVANCE

A. Scalability

Underwater Sensor Network (UW-ASN) systems may involve different entities, such as network nodes or other agents (e.g. plants, aquatic animals, microscopic organisms). UW-ASNs system scale depends on the deployment characteristics such as the environment, the application, or the users, or it can be change with time whenever needed. The term "scale" may refer to the number of nodes used inside the oceanic bodies (fewer or more nodes in the overall system), spatial density (fewer or more nodes in a high density area of the system), or the dimension of the geographical region under coverage (smaller or wider, 2D or 3D). The ability of a system to easily/transparently adapt itself to these dynamic changes in scale is named *scalability*.

Scalability might be of a great importance for most UW-ASN applications. For instance, in an environmental monitoring application, the network may need up to thousands of nodes in order to cover the whole area, depending on the required sensing information granularity (more sensor density leads to richer information, but also to more information to transmit and process) and on the transmission range of the sensor nodes. In such a case, the deployed network protocols must scale well with the number of nodes in a region, to continually ensure the correct behavior of the application. In addition, the system should adapt itself to these scale changes in a transparent way, i.e. without requiring (or with a minimum) user intervention.

Although a very large number of processors and sensors can operate in parallel and hence the processing and sensing capabilities increase linearly with the number of UW-ASN nodes, the communication capability unfortunately does not. Due to unreliability of the radio link quality, message collisions and to the multihop nature of communications, QoS can be severely affected by the increase in the network scale. Therefore, UW-ASN communication protocols and mechanisms must encompass scalability. Medium Access Control (MAC) and routing mechanisms must be scalable, otherwise problems such as uncontrolled routing and medium access delays as well as overflow of routing tables may occur. Scalability must also be taken into consideration for achieving efficient data processing, aggregation, storage and querying in UW-ASNs, especially when large amounts of data are involved

B. *Timeliness*

The timing behavior in UW-ASNs is becoming increasingly important, mainly due to the growing tendency for a very tight integration and interaction between embedded computing devices and the physical environment, via sensing and actuating actions [8].

Timeliness represents the timing behavior of a system, both in terms of computations and communications, encompassing issues such as message transmission delay (how long does it take for a message to be transmitted from source to destination, task execution time, task and message priority, network bandwidth/throughput, etc. The unique problem of the underwater acoustic communication channel is high propagation delays which require new efficient and reliable data communication protocols. The propagation delay for the underwater acoustic sensor network is five orders of magnitude higher than in radio frequency (RF) terrestrial channels, which is due to the low speed of sound (1500 m/s) in water.

Some applications specific tasks/applications within an application of UNWS need to be finished within a certain time limit (deadline). These are usually referred to as "real-time" applications/tasks and require real-time computation (requiring real-time operating systems and programming languages) and real-time communications (requiring real-time communication protocols). For instance, in a UW-ASN there is a node that detects earthquake on ocean bed in certain region and communicate this information to a remote sink within 15 seconds.

Note that the communication of UW-ASN much depends on the hardware and efficient resources utilizations. Difficulty arises in designing UW-ASN system when we rely on traditional resources allocation approach in real time system which reduces their ability to tackle the dynamic behavior of physical phenomena. . On the other hand, UW-ASN systems based on unattended resource-constrained nodes, must optimize resource utilization and heavily depend on the dynamic nature of their environment.

C. *Reliability/Robustness*

Robustness refers to the fact that a component or a system performs well in different aspects of environment not only under ordinary conditions, but also under abnormal conditions that violate its designers' assumptions. Both hardware and software system components must be robust to be resistant and adaptive to sudden and/or long-term changes. An algorithm/protocol (e.g. for routing, localization, mobility) is robust if it continues operating correctly despite abnormalities (e.g.in inputs, calculations) or despite the change of its operational conditions or its network/system structure.

On the other hand, *Reliability* is the ability of a system or component to perform its required functions under predefined conditions for a specified period of time. This is especially important in UW-ASNs, since it may be extremely difficult or even impossible to access them again once they are deployed in water. In such applications, nodes are expected to live as long as possible. To achieve these high levels of reliability, UW-ASNs must be robust and support fault-tolerance mechanisms. In addition, depending on the application and environment characteristics and requirements, UW-ASN hardware (AquaNodes)[2] must be resistant to potentially harsh environmental conditions such as salinity of water , pressure due to depth ,algae depositions and wear and tear due to attack of marine animals. Moreover, UW-ASN nodes multi-hop nature of the communication and limited availability of resource worsen the situation. As a consequence, considering robustness and reliability becomes a must in the design process of UW-ASNs to overcome the impact of these harsh operational conditions, thus mitigating maintenance actions and maximizing system lifetime.

D. *Mobility*

Mobility will be a key issue in UW-ASNs as at least some nodes/agents are likely to be physically or logically moving relatively to each other. Physical mobility mainly refers to the movement of nodes up and down in water bodies or changes in nodes geographical locations during time. Logical mobility refers to the dynamic changes in the network topology such as adding or removing new entities to/from the system. Mobility can be classified according to the type of mobile entity into three classes: (1) *Node mobility:* (mobile nodes, node clusters, routers and gateways), (2) *Sink Mobility:* (data sinks may be moving, either on purpose (e.g. data mules) or due to the application requirements), (3) *Event Mobility:*(which means that the events physically move from one location to another, such as in event detection/tracking). Mobility support significantly the capabilities of a UW-ASN system, namely: to minimize or balance energy consumption, to repair or extend the network connectivity [15] [16], However, in many application scenarios it is not enough that the UW-ASN protocol supports joining and leaving of nodes, since this process might lead to inadmissible network inaccessibility times (unbounded message delays or message losses). Mobility support in UW-ASNs is therefore a rather heterogeneous and challenging topic.

E. *Security*

Given the interactive and pervasive nature of UW-ASNs, security is one of the key points for their acceptance outside the research community. In fact, a security breach in such systems can result in severe privacy violations and physical side effects, including property damage, injury and even death.

Security in UW-ASNs is a more difficult long-term problem than is today in desktop and enterprise computing. In fact, such objects that are in spatial proximity cooperate among themselves in order to jointly execute a given task. It follows that there is no central, trusted authority that mediates interaction among them. Furthermore, UW-ASNs use wireless communication in order to simplify deployment and increase reconfigurability. So, unlike a traditional network, an adversary with a simple radio receiver/transmitter can easily eavesdrop as well as inject/modify packets in a wireless network.

While security in terrestrial WSNs has been progressive research in UW-ASN security is still in nascent stages. The limited energy resources significantly impact the availability of a robust security technique considering node's power draining vulnerability. Research in security will be key to develop underwater applications using sensor networks. Power required to process cryptic messages (encryption and decryption) must be studied extensively before implementing a suitable security technique.

Many challenges to be addressed in securing UWSNs include data confidentiality, data integrity, synchronization of encrypted messages, secure localization and authentication of nodes for secure message transmission.

Cost reasons cause devices to have limitations in terms of energy consumption, computation, storage, and communication capabilities. This leads to constraints on the types of security solutions that can be applied. To further worsen this scenario, devices often lack adequate physical/hardware support to protection and tamper-resistance. This, together with the fact that UW-ASNs can be deployed over a large, unattended, possibly hostile area, implies that each device can be tampered with by a malicious subject.

Finally, the drive to provide richer functionalities, increased customizability and flexible reconfigurability of UW-ASNs requires the ability to dynamically download software on them [17] [18]. In fact, traditional systems have been designed to perform a fixed set of predefined functionalities in a well-known operating environment. Hence, their functionality is not expected to change during the system lifetime. This design approach can no longer be pursued in the vast majority of applications. In order to be cost-effective and operational over time, UW-ASNs must be reconfigurable for becoming customizable to different operating environments and adaptable to changing operating conditions.

However, the need for reconfigurability acts against security as it introduces new sources of vulnerability. Downloading malicious software (including viruses, worms, and Trojan horses) is by far the instrument of choice in launching security logical attacks. The magnitude of this problem will only worsen with the rapid increase in the software content of embedded systems.

F. *Energy Sustainability*

Particularly in larger-scale UW-ASNs, most of the nodes must be energetically self sustainable, as maintenance actions such as battery recharge/replacement may not be feasible or at least not convenient once a node is deployed. We don't find solar energy in considerations as the sun light does not go deep in the sea water. Currently Aquanodes[2] is powered by 60 watt-hours of Lithium Ion batteries. When all the components of the node run at full power (e.g. the communication hardware is fully powered and operates continuously and the all sensors are also fully powered and sample continuously) the battery last for 1-2 weeks of continuous operation. In sleep mode the battery last upto 1year. The desired deployment time can be achieved by varying the degrees of sensing and communication.

Energy-efficiency has been a major focus of research since the evolution of UW-ASN and in continuous advancements as yet. Energy efficiency can be defined as the ratio of the amount of work done to the amount of energy consumed. Thus, using less energy to perform the same amount of work or performing more work from the same energy input can be defined as an *efficiency gain*.

However, efficiency alone is not enough to reduce energy consumption. There are many others techniques have been proposed to maximize the lifetime of battery-power in UW-ASN nodes. The main aim of these techniques is energy conservation, which can be defined as reducing energy consumption through a reduction in the amount of work done. Conservation schemes leave the ratio of the amount of work done to energy consumption unchanged and so do not affect efficiency.

Efficiency and conservation, even in combination, prolong the lifetime of a UW-ASN system, but cannot turn it "perpetual". Therefore, energy must be collected from the surrounding environment in order to supplement batteries. The process of extracting energy from the ambient environment and converting it into consumable electrical energy is generally known as energy harvesting (or energy scavenging). Energy harvesting, along with energy efficiency and energy conservation, are the available means to enable nodes self-sustainability and to prolong system lifetime, and can all be framed within the broader concept of "Energetic Sustainability".

III. CONCLUSION

Now a days we greatly depend on embedded computing systems, so the quality of their service (QoS) has great importance, particularly for Underwater Sensor Network (UW-ASN) applications where marine animals, flora, fauna, or the water bodies environment may be severely affected by their behavior. However, the provision of QoS in UW-ASNs is very challenging due to the following problems: (1) the usually severe limitations of UW-ASN nodes (e.g. energy consumption, computational and communication capabilities and security); (2) the harsh and saline nature of the oceans (impacting e.g. node lifetime, communication reliability); (3)

the large-scale nature of most UW-ASNs (impacting e.g. timeliness, reliability, security); (4) the high interdependency between QoS properties (as they are often contradictory).

This paper aimed at identifying the most important non-functional properties that affect the overall quality of the service provided to the users scalability, timeliness, mobility, security, reliability and energy sustainability - outlining their relevance, and future research directions.

The bigger challenge seems to be how to achieve an optimal solution between QoS metrics, according to the QoS requirements imposed by each application. We envision that the solution is to conceive models, methodologies and tools for network and system planning and dimensioning, based on (multi criteria) optimization techniques. System designers must have software tools for automatically setting each and every property, parameter and mechanism of the system, trying to fulfil and balance all QoS properties. We preclude that this will only be possible in a decade or so. Enough matureness must first be achieved in each individual QoS property before holistic solutions may see the light.

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