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In Special Issue on Distributed Intelligence and Data Fusion for Sensor Systems

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Editorial

Distributed Intelligence and Data Fusion for Sensor Systems

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Abstract: Sensor systems can monitor any type of parameter which is ideal for gathering information from the real world. The next step is to promote the research of distribute intelligence in sensor systems in order to let the sensors be smart and take their own decisions, and propose new data fusion techniques and methods in order to obtain the appropriate data and accurate results. In this paper we summarise a Special Issue that tackles the distributed intelligence and data fusion for sensor systems from the perspective of coding and channel allocation, data aggregation and data storage, routing, security, mobility and distributed services. This paper introduces the reader to those main hot topics and summarises the recent advances provided by the papers published in this Special Issue.

1 Introduction

Use of intelligence, data mining and data fusion has provided new momentum in the use of sensors. They have converted Wireless Sensor Networks (WSNs) into a new brand of dynamic, autonomous and intelligent distributed sensor systems. These features enable new smart sensors to play new roles as intelligent nodes gathering, manipulating and decimating data for more reliable and secure communication whilst performing more efficiently using less energy and number crunching. How to improve power saving and energy optimisation techniques is one of the main issues in WSNs [1], thus distributed intelligence and data fusion can enhance this techniques. They can be used to improve coding and channel allocation, data aggregation and data storage, routing, security, mobility and distributed services (see Fig. 1). Their application to each field contributes to the sensor systems enrichment. Some examples of how they can be applied to the aforementioned research fields are:

1. While transmitting sensory data from local sensors to the fusion center [2], the status of wireless channels will have impact on the performance of data fusion. Intelligent coding and channel allocation reduces the energy consumption while decreasing the data distortion.
2. Efficient data aggregation solutions may be used to avoid redundant data collection and raw data storage and the amount of data transmitted on WSNs [3]. Data fusion approaches applied to data aggregation and data storage can improve the network performance and prolong WSNs lifetime.
3. Gathered sensory data should be efficiently sent to the base station, which requires intelligent routing path exploration. Data fusion in-network-processing can help to reduce the size of the sensory data that to be transmitted [4].
4. Attacks may be launched when using wireless links to delivered fused data due to the lack of physical security in WSNs [5]. Meanwhile, various security/privacy issues can be involved during the process of data fusion.
5. With mobile sensors, users can easily and more efficiently gather sensory data. The fusion task can be done in various mobile devices. Mobility models and mobile path planning of mobile devices have considerable impacts on the performance of sensory data gathering and data fusion [6].
6. Self-organising and mobile sensor networks have several problems related with mobility, dispersion, weak and intermittent disconnection, dynamic reconfiguration, and limited power availability. Appropriate distributed services can solve these problems and represent a strong impact on the information distribution [7].

In order to achieve these goals sensors systems may make use of innovative protocols and algorithms, appropriate cross-layer design, network management protocols, distributed security and privacy, distributed QoS provisioning, context sensing and context awareness, Intelligence and cognitive techniques, and collaborative in-network processing and

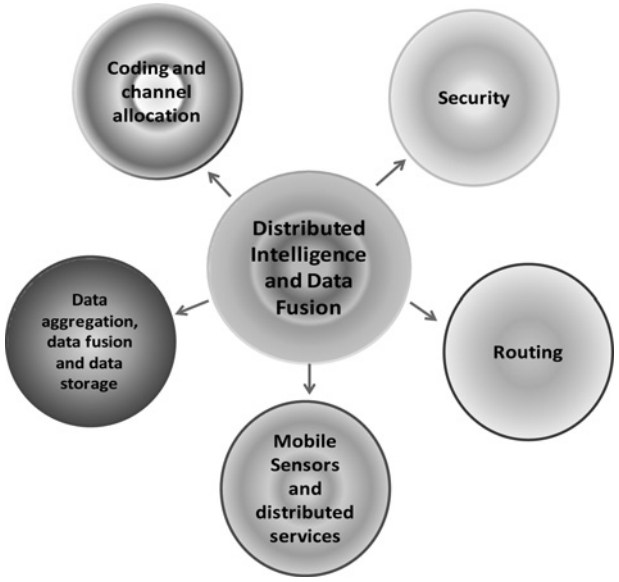

Fig. 1 *Relationship between distributed intelligence and data fusion with other research fields*

data sharing. Thus, our goal in this Special Issue is to promote the research in these topics. It aimed to present innovative and significant research papers on techniques and methods, theories and analytical proposals, experiences, test beds and practical cases of wireless sensors for use of distributed intelligence and data fusion. In this issue the topics have been discussed in terms of design, deployment, implementation, and experimental measurements and performance analysis evaluation.

The rest of the paper is structured as follows. Section 2 summarises each paper presented to this Special Issue. Finally, Section 3 provides the main conclusion and shows the future trends.

2 Papers of the Special Issue

In this section we present the papers accepted for publication in this Special Issue. We have classified the papers according to the topics: coding and channel allocation, data aggregation and data storage, routing, security, mobility and distributed services.

2.1 Coding and channel allocation

In the paper 'Adaptive Channel and Time Allocation for Body Area Networks' by Niwat Thepvilojanapong *et al.*, an adaptive scheme to allocate channel and time for coexisting Body Area Networks (BANs) is proposed. It addresses the problem that occurs when multiple BANs share wireless medium, especially a place where population density is high, a problem of packet collisions among BANs is unavoidable. The proposed scheme distinguishes inter-BAN and intra-BAN communications and adaptively allocates channel and time according to the current number of BANs that exist in a nearby area. The proposed scheme allocates time by attempting to satisfy the requirement of sampling interval determined by the application. The evaluation results demonstrate that our scheme achieves much higher packet delivery rate than an existing scheme.

Paper 'Energy-efficient scheduling of distributed estimation with convolutional coding and rate-compatible punctured convolutional coding', by Guiyun Liu and Bugong Xu, considered bandwidth-constrained distributed estimation of a deterministic parameter using wireless sensors with a fusion center. Due to bandwidth constraints, sensors' observations are quantised before transmitted directly to the fusion center. Considering the channels' imperfection, such as additive white Gaussian noise channels, channel coding technologies including repetition coding, convolutional coding and rate-compatible punctured convolutional coding, should be made fully use of. Here, convolutional coding and rate-compatible punctured convolutional coding are introduced effectively to protect signal transmission in noisy channels. Two novel kinds of power scheduling based on the above novel coding, which optimise the power allocation problem under certain constraints, are established.

2.2 Data aggregation and data storage

Wireless Sensor and Actuator Networks (WSANs) provide sensor and actuator services through small smart nodes with very limited hardware and power supply. Information fusion must be considered a critical step in WSAN design, enabling energy savings, increased quality data, and deeper insight on the monitored environment. In the paper 'Data Fusion on Wireless Sensor and Actuator Networks Powered by the ZenSens System', Neves, Rodrigues and Lin study the implementation of fusion over WSANs, in the context of the ZenSens system. It provides user-centric WSAN functionality, with IPv6 support at the sensor node level, automatic node attachment, and suitable software tools for multi-channel access. The paper presents some material about information fusion, the ZenSens system, and possible solutions for inner-node information fusion with real temperature sensor data.

In the paper 'Modelling Data-Aggregation in Multi-Replication Data Centric Storage Systems for Wireless Sensor and Actor Networks', Cuevas *et al.* introduce a novel type of sensor network, the Autonomous Wireless Sensor and Actor Network (AWSAN), in which sensor and actor nodes collaborate together in a fully distributed way to achieve a predefined goal without any central base station that manages the network. AWSAN could be deployed in remote an isolated areas that present difficult access for humans although other deployment scenarios are also possible. In addition, a multi-replication Data Centric Storage as the best data storage and delivery technology for AWSAN, leading to the novel concept of AWSAN-DCS networks is proposed. Furthermore, authors define an AWSAN-DCS application taxonomy.

The paper 'Monitoring and control Sensor System for Fish Feeding in Marine Fish Farms', presented by Garcia *et al.*, shows a feeding control system for marine fish farms. It mixes data obtained from group of sensors and takes the appropriate decisions to perform an exhaustive control on the feeding process, being able to reduce the costs and decrease the environmental impact given by residuals level accumulated in the seabed. The system takes into account the behaviour of the fishes, and some parameters from the water, and fuses the data obtained in order to decide if the fish is hungry or not.

In the paper 'Evolutionary Game Based Data Aggregation Model for Wireless Sensor Networks', by Jiawen Lin *et al.*, an evolutionary game theory is employed to establish a common model, which is independent of the specific application environments, for solving the multi-source data aggregation problem of WSNs. Guided by the model, the competition and cooperation in aggregation procedure is map into games, and then the adaptive weighting method for pixel-level aggregation with homogeneous sensors can be achieved. The experimental result shows that the proposed

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model helps to achieve the efficient data aggregation process, improve the information precision, while also telling the feasibility to some extent.

2.3 Routing

Tseng *et al.* present 'On QoS Guaranteed Cluster-based Multihop Wireless Ad Hoc Sensor Networks'. This paper proposes a quality of service (QoS) guaranteed scheduling algorithm based on distributed intelligence. Its aim is to schedule packet transmissions in both intra-cluster and inter-cluster connections in a cluster-based multihop wireless ad hoc sensor network. It uses a prioritised polling token and a local synchronisation scheme in order to analyse the maximum jitters for inter-cluster and intra-cluster constant bit rate connections and the maximum delays for intra-cluster variable bit rate connections incurred in each Cluster head. The analysed maximum jitters and delays are further used as the connection admission criterion for each newly requested connection. Both numerical and simulation results show that by using their proposal the QoS requirements of all admitted intra-cluster and inter-cluster connections are guaranteed.

Paper 'Towards Intelligent Contention-Based Geographic Forwarding in Wireless Sensor Networks', authored by Cheng *et al.*, proposes a protocol to improve the Contention-Based Geographic Forwarding routing performance in lossy links. It combats the channel variation and combines the advantages of both cooperative and contention-based forwarding. It improves the transmission reliability and avoids packet duplications by involving multiple neighbours into cooperation and sending one additional control message on demand. Simulations demonstrate that their proposal improves the routing performance by decreasing the end-to-end hop counts, so it improves the end-to-end energy efficiency, latency and packet loss ratio.

2.4 Security

Paper 'Time-Division Secret Key Protocol for Wireless Sensor Networking', contributed by Jiann-Liang Chen *et al.*, discussed a security mechanism in wireless sensor networks. The mechanism applies time-division secret key protocol to detect DoS attack. Results demonstrated that proposed protocol effectively extended the network lifetime using detection jamming scheme.

Paper 'On Centralised Conference Key Mechanism with Elliptic Curve Cryptography and Lagrange Interpolation for Sensor Networks', is contributed by Ming-Huang Guo and Der-Jiunn Deng. In this paper, the authors introduced the centralised conference key management mechanism with Elliptic Curve Cryptography and Lagrange Interpolation. The analysis showed that the proposal defeats the security attacks, and costs the control center less computation than other approaches.

In paper 'Geomorphic Zonalisation of Wireless Sensor Networks Based on Prevalent Jamming Effects', Misra *et al.* propose a scheme that demarcates the geographical extent of Wireless Sensor Networks under attack of a jammer into different zones as per the severity of jamming experienced by various nodes of the network. The proposed scheme performance is studied by the authors in detail and they do not have any inherent inaccuracies.

In the paper entitled by 'Efficient Sensor Node Authentication in 3G-WSN Integrated Networks' Hyusuk, *et al.* propose an authentication and key agreement protocol that efficiently reduces the overall computational and communication costs in the next generation converged network. The advent of converged environment merged with wireless sensor networks and mobile networks can have the possibility on enabling us to experience variety of ubiquitous applications based on multi-sensor attached smartphones. The enhanced security procedures are operated through the mobile network in order to maximise the lifetime of the sensor networks and to apply the combined capabilities of both networks.

RFID-based sensor systems are emerging as a new generation of wireless sensor networks by inherently integrating identification, sensing, communications and computation capabilities. Security and privacy problems are critical issues in dealing with a large amount of identified and sensed data. In the paper entitled by 'Scalable and Distributed Key Array Authentication Protocol in RFID-based Sensor Systems' Huansheng Ning, *et al.* propose a distributed Key Array Authentication Protocol (KAAP) with index-pseudonym and partial identifier for intelligent security management. KAAP is comprehensively analysed in three aspects: logic, security and performance. The protocol is feasible and scalable in ubiquitous RFID-based sensor systems for intelligent management.

2.5 Mobility

Over the last decade, mobile agent (MA) systems for multimedia and surveillance applications in wireless sensor networks have gained much attention. In the paper 'Multiple Mobile Agents Itinerary Planning in Wireless Sensor Networks: Survey and Evaluation' by Wang *et al.*, the itinerary planning issues for using multiple Mobile Agents (MAs) in WSNs are discussed, including deciding the number of MAs to be dispatched, grouping of source nodes for each MA, routing of each MA for its assigned source nodes and etc. And also the authors survey the existing algorithms for these issues and evaluate their performance by OPNET.

2.6 Distributed services

In paper 'Distributed Service Integration for Disaster Monitoring Sensor Systems', Liu *et al.* propose new architectural model of dynamic distributed service integration for disaster monitoring sensor systems which can proactively self-adapt to changes and evolution occurring in the provision of search and rescue capabilities in a dynamic environment. They demonstrated through simulations that the proposed model can achieve enhanced performance for the provision of rescue capability in a scenario of disaster area monitoring.

3 Conclusion and future trends

We have seen in this Special Issue how distributed intelligence and data fusion can be applied to sensor systems by means of coding and channel allocation, data aggregation and data storage, routing, security, mobility and distributed services. Distributed intelligence and data fusion techniques have provided many benefits to the field of sensor systems, by making them more adaptable, flexible, smart, secure and scalable while improve their performance. Future trends in sensor systems are focused in adding cognitive science at all communication levels. We have observed many research works introducing cognitive science at the physical and MAC communication layer and it is expected to be added in higher layers, in security and in cross-layer optimisation techniques.

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