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Multi-Core Embedded Wireless Sensor Review & Applications

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Abstract— **Single chip contains millions of transistors. To develop this high density system, embedded systems are come in for an alteration from single-core to multi-core. Although a bulk of embedded wireless sensor networks (EWSNs) consist of single-core embedded sensor nodes, multi-core embedded sensor nodes are visualized to expand in special application areas that needs complicated intra-network processing of the sensed data. In this paper, we studied architecture for diverse hierarchical multi-core embedded wireless sensor networks (MCEWSNs) and an architecture for multi-core embedded sensor nodes used in MCEWSNs. Next we talk about research challenges and future research directions for MCEWSNs.**

***Keywords*— Wireless sensor networks, multi-core, embedded systems.**

I. INTRODUCTION

Embedded wireless sensor networks (EWSNs) contains sensor nodes by way of embedded sensors to intellect data regarding a happening and these sensor nodes reverse with adjacent sensor nodes over wireless links. Many promising EWSN application (e.g., observation, volcano watching) needs a excess of sensors (e.g., auditory, seismic, warmth, and, in recent times, image sensors and/or smart cameras) implanted in the sensor nodes. Although usual EWSNs prepared with scalar sensors (e.g., temperature, humidity) transmit most of the sensed information to a information taker node (base station node), this sense and transmit prototype is becoming infeasible for information eager applications ready with a in temperance of sensors ,together with image sensors and/or smart cameras. Processing and transmission of the huge quantity of sensed data in rising applications exceed the capability of usual EWSNs. For example, think about a military EWSN deploy in a battleground, which needs different sensors.

Dispensation and changing of the huge sum of sensed data in rising applications exceeds the capabilities of conventional EWSNs. For example, think about a military EWSN deploy in a battleground, which needs different sensors such as imaging, auditory, and electromagnetic sensors. This purpose presents a variety of challenges for current EWSNs as transmission of high-resolution images and video streams over bandwidth-limited wireless links from sensor nodes to the sink node is infeasible. Additionally, significant processing of multimedia information (audio, image, and video in this example) in coincident exceeds the capabilities of usual EWSNs having single-core embedded sensor nodes [2], [3], and requires additional influential embedded sensor nodes to recognize this application.

As single-core EWSNs will almost immediately be incapable meeting the rising necessities of data-rich applications (e.g., video sensor networks), next age group sensor nodes have to acquire improved calculation and conversation abilities. For example, the transfer speed for the first age group Mica motes was 38.4 kbps whereas the second age group Mica motes (MicaZ motes) can conversed at 250 kbps using IEEE 802.15.4 (Zigbee) [3]. Regardless of these improvements in conversation, partial wireless bandwidth from sensor nodes to the sink node makes appropriate transfer of multimedia information to the sink node is not possible. In usual EWSNs, the communication power suppressed the communication power suppressed the computation energy. Opportunely, there exists a trade off between transports and calculation in an EWSN, which is well-matched for within-network processing for data-rich applications and permits transport of just event descriptions (e.g., detection of a target of interest) to the sink node to safeguard power. Technical enhancements in multi-core designs have prepared multi-core processors a feasible and cost efficient alternative for growing the computational capability of embedded sensor nodes. Multi-core embedded sensor nodes can mine the most wanted data from the sensed data and converse only this processed data, which reduces the data transfer capacity to the sink node. By changing a great percentage of conversation with networked computation, multi-core embedded sensor node can understand huge power saving which would increase the sensor network's total life span.

Multi-core embedded sensor nodes make possible power reserves over conventional single-core embedded sensor nodes in two methods. First, reducing the energy exhausted in conversation by performing in-situ computation of sensed data and transferring simply processed information.

Second, as compared to a single-core system, a multi-core embedded sensor node permits the calculations to be divided across several cores while executing each core at a minor processor voltage and frequency, which cause power savings. For information processing, utilizing a single-core embedded sensor node in data-rich applications needs the sensor node to execute at a high processor voltage and frequency to meet the application's delay requirements, it increases the power dissipation of the processor. A multi-core embedded sensor node decreases the number of memory accesses, clock speed, and instruction decoding, thus enabling advanced mathematics presentation at a low power utilization on comparison with single-core processor.

The alternative of a multi-core architecture prescribes the high level Simultaneous languages as some multi-core architectural design help proprietary parallel languages whose touchstones are not available open source (e.g., Tilera's TILEPro64). Tilera provides a multi-core development environment (MDE) ilib API but many SMPs (e.g., the Intel-based SMP) support OpenMP (Open Multiprocessing),thus the cross-architectural assessment results might be exaggerated by the parallel language's efficiency. However, our examination provides insights into the possible performance per watt from these two multi-core architectures for MCEWSNs.

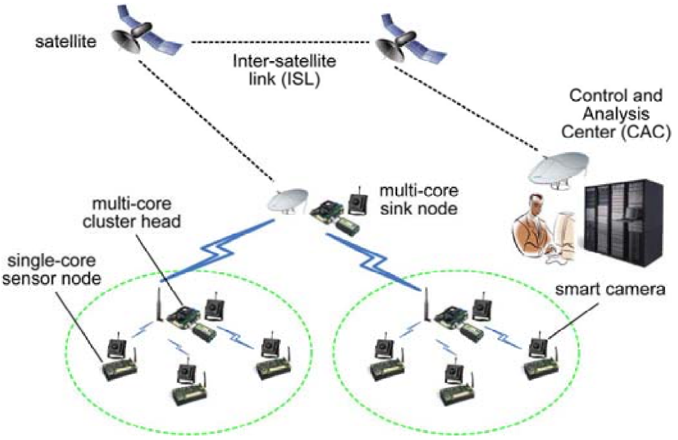

Fig. 1. A heterogeneous multi-core embedded wireless sensor network (MCEWSN) architecture.

II. MULTI-CORE EMBEDDED WIRELESS SENSOR NETWORK ARCHITECTURE

Fig. 1 shows diverse hierarchical MCEWSN architecture, which fulfills the rising intra-network computational needs of promising EWSN applications. The diversity in the architecture subsumes the combination of several single-core embedded sensor nodes and a number of multi-core embedded sensor nodes. It is noted that harmonized hierarchical single-core network.

The control and analysis center additionally investigates the information gained from the sink node and produces control commands and queries to the sink node.

MCEWSNs could be attached with a satellite backbone network that provides long-haul conversation from the sink node to the control and analysis center as MCEWSNs are frequently used in remote zones with no wireless arrangements, like a cellular network set-up. The satellites in the satellite backbone network converse with each other through inter satellite links (ISLs). As a satellite's uplink and downlink bandwidth is restricted, a multi-core processor in the sink node is needed to process, compress, and/or encrypt the data sent to the satellite backbone network. Each cluster contains numerous child sensor nodes and a cluster head. Child sensor nodes consists a single-core processor and are accountable for sensing, pre-processing sensed information, and transferring sensed information to the cluster head nodes. Since child sensor nodes are not aimed to do complicate processing of sensed information in this architecture, a single-core processor adequately encounters the computational necessities of child sensor nodes. Cluster head nodes contains a multi-core processor and are accountable for coalescing/fusing the data received from child sensor nodes for transfer to the sink node in an energy- and bandwidth-efficient way. This architecture with multi-core cluster heads is built on real-world causes as distributing all the composed information from the cluster heads to the sink node is not possible for bandwidth restricted EWSNs, which permits composite treating and data synthesis to be carried out at cluster head nodes and solitary the brief treated data is transferred to the sink node. The sink node consists a multi-core processor and is accountable for altering high-level user queries from the control and analysis center (CAC) to network-specific directions, quizzing the MCEWSN for the needed information, and recurring the wished information to the user/CAC. The sink node's multi-core processor eases post-processing of the data gained from many cluster heads. The post-processing at the sink node includes information synthesis and event discovery based on combined data from all of the sensor nodes in the network. The CAC further examines the data received from the sink node and produces control commands and queries to the sink node.

MCEWSNs could be joined through a satellite backbone network that offers long-haul conversation from the sink node to the CAC since MCEWSNs are frequently organized in remote areas with no wireless substructure, such as a cellular network substructure. The satellites in the satellite backbone network conversation with one another through inter satellite links (ISLs). Since a satellite's uplink and downlink bandwidth is restricted, a multi-core processor in the sink node is needed to process, compacted, and/or encrypt the data sent to the satellite backbone network.

Although this paper emphases on diverse MCEWSNs, uniform MCEWSN architectures are an extension of given architecture (Fig. 1) where child sensor nodes also consists a multi-core processor. In a uniform MCEWSN fortified with multiple sensors, each processor core in a multi-core embedded sensor node could be allocated to process one sensing job (e.g., one processor core handles sensed temperature data and other processor core grips sensed humidity data and so on) as contrast to single-core embedded sensor nodes where the single processor core is accountable for processing all of the sensed data by whole the sensors. We emphasis on diverse MCEWSNs as we trust that diverse MCEWSNs would serve as a primary step in the direction of combination of multi-core and sensor networking technology since the subsequent reason. Due to the_supremacy of single-core embedded sensor nodes in current EWSNs, substituting all of the single-core embedded sensor nodes with multi-core embedded sensor nodes may not be possible and economical given that only a few multicore embedded sensor nodes functioning as cluster heads can meet an application's intra-network calculation necessities. Therefore this varied MCEWSN would support a smooth transition from single core to multi-core EWSNs.

III. MCEWSN APPLICATION DOMAINS

MCEWSNs are proper for sensor networking application as which needs complicated in-network data processing such as terrestrial hybrid sensor networks, wireless video sensor networks, satellite-based wireless sensor networks, space shuttle sensor networks, aerial, wireless multimedia sensor networks and fault-tolerant sensor networks.

A. Wireless Video Sensor Networks (WVSNs)

Wireless video sensor networks (WVSNs) are WSNs, sensor nodes are embedded with smart cameras and/or image sensors. WVSNs match the compound eye found in certain arthropods. WVSNs are appropriate for applications in areas such as native land security, battlefield observing, and mining. For example, video sensors provide a level of continuous and accurate monitoring and protection deployed as airports, borders, and harbors that is otherwise unattainable.

In image-centric WVSNs, several image/camera sensors detect a sight from many sides and are capable to define entities in their true three-dimensional form by removing obstruction problems. Image preprocessing includes complications and data-dependent processes by a restricted neighborhood of pixels. Video-centric WVSNs trust on numerous video streams from multiple embedded sensor nodes. Since sensor nodes could individual serve low-resolution video streams provided the sensor nodes' resource restrictions, a single video stream only does not contain sufficient data for visualization analysis like event detection and tracking, though, multiple sensor nodes could capture video streams by different viewpoints and distances together giving vast visual data [4]. Video encoders depend on intra frame compression methods that decrease duplicity inside one frame and inter frame compression techniques (e.g., predictive coding) which exploit duplicity between subsequent frames [2]. Video coding procedures needs complicated algorithms which overflow the computing power of single-core embedded sensor nodes. The visual data from various sensor nodes might be collected to provide high-resolution Video streams, still, this processing necessitates multicore embedded sensor nodes and/or cluster heads.

B. Wireless Multimedia Sensor Networks (WMSNs)

A wireless multimedia sensor network (WMSN) involves wirelessly linked embedded sensor nodes which could retrieve multimedia content such as video and aural streams, motionless images, and scalar sensor data of the examined occurrence. WMSNs goal a huge types of distributed, wireless, streaming multimedia networking applications ranking from home scrutiny to army and space applications. A multimedia sensor catches aural and image/video streams via an embedded microphone and a micro-camera, achieve application objectives.

While the sensing capacity in many sensors is isotropic and reduces as distance increases, a different quality of video/image sensors of these sensors' directional sensing ranges. Recently, Omni cameras have become available, it can deliver whole coverage of the scene nearby a sensor node, but, applications are restricted to nearby range scenarios to assurance satisfactory image resolution for objects in motion [4]. To confirm whole coverage of the sensor arena, a group of directional cameras are needed for capturing sufficient data for activity detection. The image and video sensors great sensing cost limits these sensors constant triggering specified constrained embedded sensor node resources. So, the image and video sensors in a WMSN need complicated control such that the image and video sensors are initiated only later a objective is detected based on sensed data from another inferior cost sensors, such as auditory and electromagnetic. Desired WMSN features consist of the capacity to store, process in real-time, associate, and fuse multimedia data originating from dissimilar sources [2]. Multimedia contents, especially video streams, need data rates that are orders of magnitude greater than those supported by customary single-core embedded sensor nodes. To refine multimedia data in real-time and to decrease the wireless bandwidth requirement, multi-core embedded sensor nodes in the network are needed. Multi-core embedded sensor nodes enable in-situation processing of enormous information from many sensors, notifying the CAC at once an event is spotted e.g., target detection.

C. Satellite-Based Wireless Sensor Network (SBWSN)

A satellite-based wireless sensor network (SBWSN) is a wireless communication sensing network comprised of numerous satellites, each one prepared with multi-functional sensors, lengthy range wireless information exchange units, thrusters for attitude adjustment, and a computational unit (potentially multicore)to carry out handling of the sensed data. Conventionally satellite assignments are extremely costly to design, build, launch, and operate, thus motivating the aerospace industry to emphasis on dispersed space missions, which would contains of many small, low-cost, and spread satellites harmonizing to achieve mission aims. SBWSNs could empower robust space operations by bearing the failure of a particular or a few satellites as compared to a large particular satellite, where a single failure could settled the attainment of a process. SBWSNs can be used for a range of missions, such as space weather monitoring, studying the impact of solar storms on Earth's magnetosphere and ionosphere, environmental observing e.g., pollution, land, and ocean surface monitoring, and hazard forecast e.g., flood and earthquake forecast.

Each SBWSN mission requires specific orbits and constellations to meet mission requirements and GPS provides crucial tool for orbit determination and routing.

Satellites in an SBWSN can be used as an interferometer, which correlates different images acquired from slightly different angles/view points in order to get better resolution and additional significant intuitions.

All of the satellites in an SBWSN collaborate to sense the desired phenomenon, communicate over lengthy distances through beam-forming above an ISL, and maintain the network topology through self-organized mobility [14].

VI. RESEARCH CHALLENGES AND FUTURE

RESEARCH DIRECTIONS

In spite of some inventiveness pointing MCEWSNs, the domain is further in its inception and needs addressing few provocations to open doors for ubiquitous exploitation of MCEWSNs. In this part, we talk about some research challenges and upcoming research guidelines for MCEWSNs.

A. Application Parallelization

Parallelization of current sequential appliances and algorithms could be tricky taking into consideration the restricted number of concurrent developers on comparison with sequential developers. Concurrent software applications with restricted scope, current challenges for competent deployment of multi-core and future many-core embedded sensor nodes. Additionally, harmonization among diverse cores by the utilization of obstacles and locks limit the achievable accelerate by concurrent software applications deprived acceleration due to restricted scalability as the number of cores raise could reduce the power and proficiency profits fulfilled by concurrency of sensor applications. To reduce latent proficiency deprivation for parallel applications with restricted scalability ,designers can limit these applications to a restricted number of cores as switch off left over cores to save energy or utilizing other cores by multiprogramming other sensor applications on those cores. Accordingly, present operating systems for embedded sensor nodes (e.g. TinyOS) would require renovating their arrangers for proficient arrangement of multi-programmed workloads and would as well need some middleware support (e.g., OpenMP) to support multi-processing of parallel applications.

B. Reconfigurability

Reconfigurability in MCEWSNs is an important research avenue that would allow the network to adapt to new requirements by integrating code upgrades (e.g., a more efficient algorithm for video compression may be discovered after deployment). Mobility and self-adaptability of embedded sensor nodes requires further research to obtain the desired view of the sensor field (e.g., an image sensor facing downward towards the earth may not be desirable).

C. Energy Harvesting

Considering that the battery energy is the most critical resource constraint for sensor nodes in MCEWSNs, research and development in energy-efficient batteries and energy harvesting systems would be beneficial for MCEWSNs.

D. Heterogeneous Architectures

MCEWSNs would benefit from parallel computer architecture research. Specifically, a heterogeneous many-core architecture that could leverage both super- and near threshold computing to meet performance and energy requirements of sensing applications might provide a promising solution for MCEWSNs. The heterogeneous architecture can integrate super-threshold (nominal voltage) SMP cores and near-threshold single instruction multiple data (SIMD) cores. Research indicates that a combination of NTC and parallel SIMD computations achieves excellent energy efficiency for easy-to-parallelize applications. With this heterogeneous architecture, sensing applications' tasks with less parallelism can be scheduled to high-power SMP cores whereas tasks with abundant parallelism will benefit from scheduling on low power near-threshold SIMD cores. Hence, research in heterogeneous architectures would enable a single architecture to serve a broad range of sensing applications with varying degrees of parallelism.

V. CONCLUSION

We studied an architectural design for diverse hierarchical multi-core embedded wireless sensor networks (MCEWSNs). Compute-intensive jobs as data blending, encryption, network coding, and software defined radio, will benefit in particular from the improved computational power presented by multi-core embedded sensor nodes. Several wireless sensor networking application areas, such as space shuttle sensor networks, wireless video sensor networks, satellite supported sensor networks, aerial-terrestrial amalgam sensor networks, wireless multimedia sensor networks, and fault-tolerant sensor networks, could take advantage from MCEWSNs. Perceiving the prospective profits of MCEWSNs, some initiatives have been undertaken in both academic world and industrial world to build up multi-core embedded sensor nodes, such as IntraNode, satellite-supported sensor nodes, and smart camera specks .We also involved the research threats and future research pathways for MCEWSNs.

Specifically, MCEWSNs would profit from betterments in application parallelization, diverse architectures, and transistor technology.

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