Pervasive and Mobile Computing 22 (2015) 16–32

Contents lists available at ScienceDirect

Pervasive and Mobile Computing

journal homepage: www.elsevier.com/locate/pmc

EMCOS: Energy-efficient Mechanism for Multimedia Streaming over Cognitive Radio Sensor Networks

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A R T I C L E   I N F O

Article history:
Available online 25 June 2015

Keywords:
WSN
Cognitive radio
Multimedia
Qos
Energy

A B S T R A C T

One of the major challenges for multimedia transmission over multimedia WSN (MWSN) in urban environment is the scarcity of spectrum combined with high radio interference. Such environment makes it difficult to ensure high bandwidth, low delay and low packet losses required for real time multimedia streaming applications. We target a scenario of video surveillance in urban environment which not only requires efficiency of spectrum utilization, but also requires energy efficient mechanisms for the battery operated MWSN nodes. In this paper, we propose a new solution for multimedia transmission over WSNs which uses cognitive radio technology for spectrum efficiency and clustering mechanism for energy efficiency. A video streaming solution is proposed that is called "EMCOS: Energy-efficient Mechanism for Multimedia Streaming over Cognitive Radio Sensor Networks". EMCOS ensures high quality real time multimedia transmission from one or more sources to a given sink, under different spectrum availability conditions, while efficiently using the energy of the MWSN nodes. First, EMCOS clusters the MWSN nodes into different clusters in order to ensure low energy consumption. Additionally for clustering, EMCOS not only takes into consideration the geographic positions, but it also takes into account the actual and the forecast of the channel availability in order to ensure stable clusters. Once the clusters are built, a cluster head is elected for each cluster in a way which preserves the cluster energy by considering the energy utilization of all cluster members. Further, to ensure the content delivery from the source to the sink, a routing/channel selection mechanism is proposed. The channel selection is based on PU activity forecasts to prevent frequent channel switching. Simulations show that our proposal EMCOS outperforms the two existing pioneering mechanisms called SEARCH and SCEEM. EMCOS outperforms them in terms of providing higher video quality, lower end-to-end transmission delay and lower frame loss ratio under varied spectrum conditions.

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1. Introduction

Radio communications need efficient and adaptive mechanisms to tackle issues related to inherently challenging radio environment and scarcity of radio spectrum. In this context, Cognitive Radio (CR) is becoming a promising technology

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http://dx.doi.org/10.1016/j.pmcj.2015.06.015
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that enhances the performance of radio communication and improves the efficiency of radio spectrum utilization by enabling flexible and adaptive radio capabilities. Such CR capabilities are enabled by combining artificial intelligence, software-defined radios and opportunistic radio spectrum access schemes. Cognitive Radio was defined by Joseph Mitola [1] as intelligent radio that can autonomously make decisions using gathered information about the radio frequency (RF) environment through model-based reasoning and can also learn and plan according to its past experience. Later, Simon Haykin [1] defined CR as an intelligent wireless communication system capable of being aware of its environment, learning, and adaptively changing its operating parameters in real time for providing reliable communication and efficient utilization of the radio spectrum. Such intelligent radios use model-based reasoning, and they learn and adapt based on their past experiences. This definition was extended to CR as an intelligent wireless communication system whose goal is to provide reliable communication and efficient utilization of the radio spectrum. This is achieved through the CR capabilities of environment awareness, real time learning and real time adaptation of its operating parameters such as transmission power, carrier frequency and modulation. CR uses opportunistic radio spectrum access techniques such that the unlicensed users, or secondary users (SUs), continuously monitor the presence and activity of the licensed users, or primary users (PUs), to find the spectrum holes. This monitoring is done by different spectrum sensing techniques and spectrum holes are the bands which are not being utilized by PUs at a given time or a given location. The SUs can opportunistically utilize these spectrum holes and they should ensure no interference with the PUs.

Cognitive Radio is a promising communication technology for Wireless Sensor Networks (WSNs) [1]. Its opportunistic communication paradigm suits wireless sensor networks that carry bursty traffic due to their event driven nature. Cognitive Radio can help overcome the problems of collision and excessive contention in WSNs that arise due to the deployment of several sensors connected through radio links. In comparison, conventional WSNs use fixed spectrum allocation policy and their performance is limited due to low processing and communication power of sensor nodes which are typically resource-constrained. However, WSNs operate over unlicensed bands which are becoming saturated due to a significant growth in the number of wireless applications using the same bands. Thus, the challenge is to efficiently utilize the spectrum and this challenge can be addressed by using cognitive radio technology for WSNs.

Using CR technology for WSNs leads to a new paradigm called cognitive radio sensor networks (CRSN). A CRSN consists of wireless cognitive radio sensor nodes, which sense an event and collaboratively communicate the information using radio spectrum in an opportunistic manner. Using CR technology in resource-constrained WSNs improves the spectrum utilization, enables multi-channel capability and overcomes the problems related to dense deployment of WSNs or higher communication performance required in some WSN applications.

One potential application of CRSN is Multimedia Wireless Sensor Networks (MWSN). MWSN consists of sensor nodes having low cost cameras and microphones. Multimedia sensor nodes are used to store, process and transmit video, audio and image data for the applications such as tracking and monitoring.

We consider video surveillance in urban environment as the candidate scenario for multimedia streaming with cognitive radio sensor networks. In this scenario, multimedia sensor nodes equipped with cameras are connected with wireless links in ad hoc manner. One or more of these nodes are active at the same time. They continuously monitor the environment and transmit the captured videos to the sink node. These nodes operate on batteries and hence energy efficiency is an important issue for this system. Moreover, for wireless transmission of video the spectrum should be utilized efficiently as nowadays spectrum in cities is a scarce resource. The licensed spectrum bands (3G, 4G, etc.) are highly utilized and the unlicensed spectrum bands such as ISM bands are becoming highly saturated. That is why we propose an energy efficient approach based on cognitive radio for an efficient utilization of the spectrum.

The key issues and challenges of MWSN are high bandwidth demand, high energy consumption, quality of service (QoS) provisioning, data processing, and compressing techniques, and cross-layer design:

- MWSN requires high bandwidth in order to deliver multimedia content such as a video stream, audio stream or images. Providing high bandwidth can be challenging with conventional WSNs which use fixed spectrum allocation and operate over saturated unlicensed bands.
- Multimedia transmission requires certain QoS guarantees. However, QoS provisioning is very challenging in WSNs as radio links can have variable capacity and delay. Nevertheless, in MWSNs, a certain level of QoS must be achieved for reliable delivery of multimedia content.
- Energy efficiency is very important for MWSN as sensor nodes typically have low energy resources. Thus, mechanisms need to be designed that focus on energy efficient communication to exploit transmission power and spectrum characteristics vs. performance and reliability trade-off.
- Efficient spectrum utilization, as discussed above, is important because of scarce nature of radio spectrum. Thus, a dynamic spectrum allocation scheme is needed for MWSNs that can take into account the application requirements in terms of bandwidth, QoS and traffic load.

CR technology can answer the above requirements of MWSNs. CR can provide extra bandwidth and improve the quality of service. However, such cognitive radio approaches, specific to MWSNs, need to be designed which focus on energy efficient communication to exploit transmission power and spectrum characteristics vs. performance and reliability trade-off. In addition, low cost algorithms need to be designed for spectrum sensing and dynamic spectrum usage. Most of the works in the literature focusing on CRSNs are related to only spectrum sensing [2–4]. A few works focus on multimedia transmission over cognitive radio networks [5–8], but they do not consider the WSN environment and the related constraints.

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