A Distributed EMI-aware Routing Algorithm for Wireless Sensor Networks in Clinical Environments

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hSITE

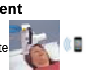
(hSITE: Healthcare Support through Information Technology Enhancements)

Abstract

This work proposes an adaptive and distributed routing protocol that attempts to reduce electromagnetic interference (EMI) introduced by wireless medical sensor networks. The proposed algorithm, namely EMI-aware routing (EMIR), assigns to each network node a potential value which is dynamically calculated in such a way that radio activities are spatially spreaded out. This results in a lower probability that operations of medical devices are affected. EMIR only requires one-hop neighbor information and does not require flooding of control messages in the whole network, therefore it scales well to the network size.

1. Motivations and Contributions

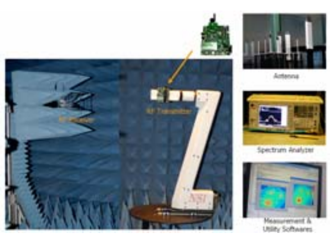
- The use of **wireless communications technology** can significantly **improve the quality** and **reduce the cost** of **healthcare services**
- However, **electromagnetic energy** radiated by wireless devices potentially affects the operation of **sensitive patient monitoring equipment**
- Many incidents have been documented
  - A ventilator suddenly changes its breath rate
  - An apnea monitor fails to alarm



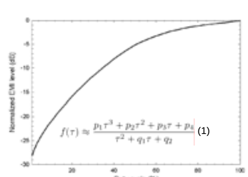
- Hospitals have implemented different policies
  - Total ban of mobile communication devices
  - Restrictions to the use of wireless devices in critical areas
  - "Minimum separation criterion"
- This work addresses the problem of adaptive routing that attempts to **reduce the EMI** introduced by a wireless network deployed in an ER/ICU

2. EMI and Radio Duty Cycle

- An IEEE 802.15.4 compatible wireless node is used to transmit the signal at the fixed power level of 0dBm at 2.4 GHz frequency band
- The level of EMI generated by the node is measured when the radio duty cycle is varied
- In order to avoid interference from other unwanted radio sources, all measurements are performed in an anechoic chamber
- EMI receiver is set in EMI average mode that is compatible with CISPR 16-1-1 standard



EMI measurement setup

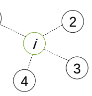


EMI against radio duty cycle

3. The proposed EMIR protocol

1. Location information of nodes is not required
2. Hop-by-hop routing framework
3. Each node is assigned with a potential value which determines the per-hop behavior of the routing protocol
4. The packet is routed to the neighbor which is currently having the lowest potential value

$$j^* = \arg\min_{j \in \mathbf{N}_i} \{P_{i,j}\}$$



- The **potential** of each node is determined by two main parameters
  - (1) Node's current radiating EMI level $f(\tau_i)$
    - calculated by (1) as a function of radio duty cycle over the an observation time window
  - (2) The distance from the node to the nearest gateway h_i
    - obtained by periodically exchanging hello messages between gateways and nodes
- Each node advertises its existence by periodically broadcasting hello messages

- Hello messsage format
  - Node identification, i.e., i.
  - τ_i: the instantaneous duty cycle of node i over the most recent observation time window w_T.
  - h_i: the minimum number of hops that a packet needs to travel from node i to reach the nearest gateway.
- Each gateway also broadcasts hello messages, however its hop parameter is always zero in order to advertise that it is the final destination and in turn shape up traffic flows
- Node i, upon receiving a hello message from node k, performs the following operations:
  - If node k is currently not in the list of neighbors of node i, then it is added into $\mathbf{N}_i$, i.e., $\mathbf{N}_i = \mathbf{N}_i \cup \{k\}$. Values of τ_k and h_k are included into neighbor information table of node i.
  - If node k is existing neighbor $v_{i,j}$, then $\tau_{i,j}$ and $h_{i,j}$ are updated by their respective new values supplied by the received hello message.
  - Node i updates the value of its parameter h_i as follows:

$$h_i = 1 + \min_{j \in \mathbf{N}_i} \{h_{i,j}\}.$$

Used to estimate the distance (hop count) from the node to the nearest gateway

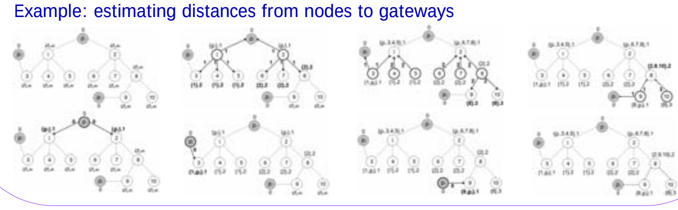
Potential of the j-th neighbour of node i

$$P_{i,j} = \left[\overline{f}(\tau_{i,j})\right]^{\alpha} \left(\overline{h}_{i,j}\right)^{\beta}$$

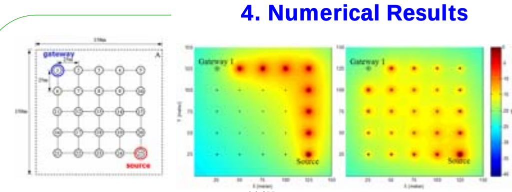
EMI distance to gateway

$$\beta(p) = \frac{[1 + h(p)]^{\gamma}}{\lfloor 0.5(N-1) \rfloor}\alpha \quad (2)$$

Example: estimating distances from nodes to gateways

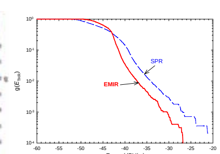


4. Numerical Results

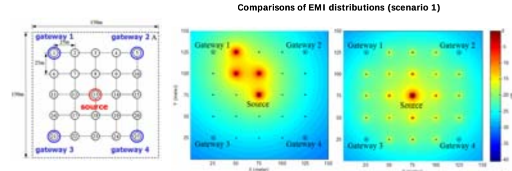


(a) SPR (b) EMIR

Comparisons of EMI distributions (scenario 1)

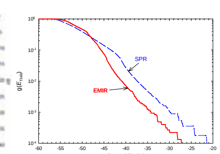


Normalized EMI-affected areas (scenario 1)



(a) SPR (b) EMIR

Comparisons of EMI distributions (scenario 2)



Normalized EMI-affected areas (scenario 2)

5. Conclusions

- The wireless routing problem with primary objective of mitigating EMI is addressed and solved in this paper
- Potential values are assigned to each node: traffic is deflected from nodes that are generating higher EMI and/or locating further away from the gateways
- The proposed protocol does not require flooding of control messages in the whole network
  - Each node autonomously determines its potential value by considering only the status of its direct neighbors
  - This enables the protocol to scale very well to the network size
- It can effectively reduce the affects that EMI may cause to medical devices by spreading the EM radiation throughout the network deployment area

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