Application-specific Routing Scheme for Indoor Wireless Localization Systems*

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ABSTRACT

The proposed research focuses on the communication in an RF-based indoor wireless localization system. In such a system, wireless *badges* attached to people or devices report positions to wireless *gateway* units. Badges have very limited communication, energy, as well as processing capabilities. However, gateways are significantly less constrained by battery than the badges. Wireless gateway units route collected badge information hop-by-hop towards one *central unit* of the system. We assume that each gateway unit has one transceiver antenna and is able to determine its own relative position in the system. The goal of this research is to develop an application-specific scheme for information routing and topology control among gateway units with maximum reliability, flexibility, adaptability and acceptable latency. We implemented two protocols (a *robust* one and a *traffic-aware* one), however, we shall show that for large networks, the use of multiple routing algorithms is beneficial. We assume that the topology control is fully centralized and the central unit is responsible for network management. We simulated the feasibility of the proposed novel two-protocol routing scheme and compared this scheme to a well-known dynamic source routing scheme. We demonstrated noticeable improvements in terms of robustness, traffic-awareness, and throughput. We also showed that the use of multiple protocols in our application-specific wireless indoor localization system will enhance the overall system performance.

Keywords: wireless sensor networks, wireless information routing, wireless localization, application-specific routing, multiple routing protocols

1. INTRODUCTION

In a wireless sensor network (WSN), communicating entities of a certain area are designed to monitor and report one or more characteristics of their environment and/or their status information. Communicating nodes tend to contain two major functional units. The first one is responsible for measuring and calculating the sensed value that can be temperature, acceleration, movement, signal strength, etc. The second functional unit, the communicating part, organizes, handles, and forwards information incoming not only from the sensor part but also from other communicating parts of other sensors. This unit is usually equipped with only one tiny omni-directional antenna (radio) and has very constrained communication opportunities and hardware.

The *wireless positioning task* is to localize nodes (as *badges*) attached to people or objects within a particular area. In an outdoor environment, localization is usually based on GPS communications. However, GPS cannot operate inside buildings or closed areas[1]. Therefore there is a need for more sophisticated methods for special-purpose indoor localization WSNs. Extensive research and development activity provided several mechanisms for the indoor localization. These are based on timing information, received signal strength, angle of arrival and signal pattern[2].

In an RF-based indoor wireless localization system, wireless badges attached to people or devices scan their wireless environment for wireless *beacon* signals. Based on the incoming signals the units calculate their positions and then become ready to communicate the location information. In this paper, we propose a novel application-specific routing scheme for indoor wireless localization systems. Our research focuses on the communication in an RF-based indoor wireless localization system. In this two-level hierarchical system, wireless badges attached to people or devices report

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Digital Wireless Communications VII and Space Communication Technologies, edited by Raghuveer M. Rao, Sohail A. Dianat, Michael D. Zoltowski, Rabindra Singh, Susan P. Miller, Proc. of SPIE Vol. 5819 (SPIE, Bellingham, WA, 2005) · 0277-786X/05/$15 · doi: 10.1117/12.606706

positions to wireless *gateway* units. Badges have very limited communication, energy, as well as processing capabilities. Each unit has the same communicating parts; from this point of view the system is *homogeneous*. However, gateways are significantly less constrained by battery than the badges. Wireless gateway units *route* collected badge information hop-by-hop towards one *Central Monitoring Station* (CMS) unit of the network (Figure 1). We assume that each unit has one ISM 900MHz-band transceiver antenna and is able to determine its own relative position in the system by listening to other units' periodic beacon signals. Furthermore, gateway units act as cluster heads and coordinate intra-cluster communication and medium access as well as interface inter-cluster transfer.

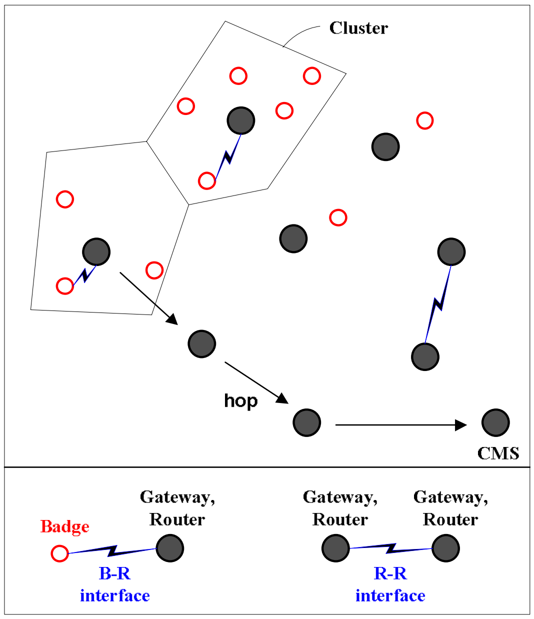

Figure 1: Multi-hopping Concept

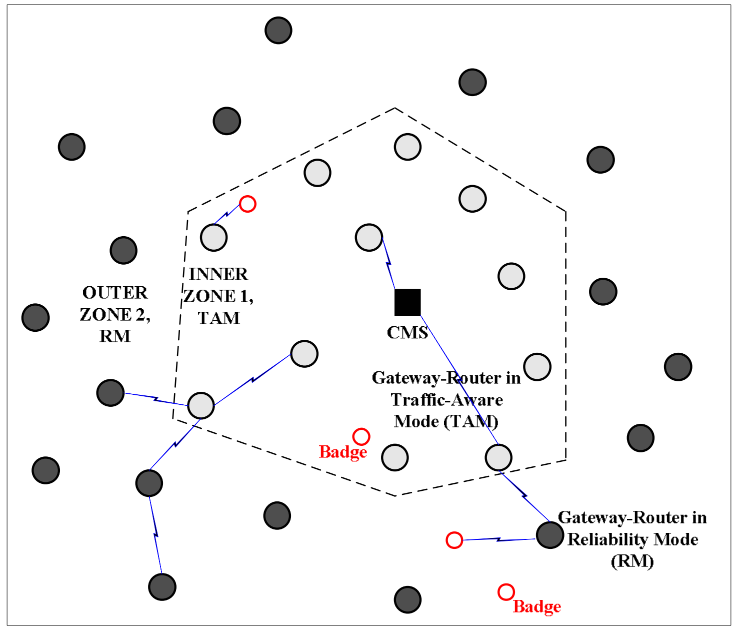

Figure 2: Traffic-Aware Mode and Reliability Mode Zones

The goal of this research is to develop an application-specific scheme for information routing and topology control among gateway units with maximum reliability, optimal flexibility, adaptability and acceptable latency. The development is based on Chipcon CC1010 Evaluation Module (EM)[3] with limited communication capabilities.

There has been intensive research on routing algorithms[4]. However, existing algorithms usually differ in individual focuses in robustness, latency, traffic-awareness, throughput, etc, but lack the complete solution to application-specific needs. For example, there is a need for more *robust* and *reliable* routing algorithm in the outer zones of the network. However, routing at locations closer to the central CMS unit is much more sophisticated and the *traffic-aware* scheme should be adapted.

This paper is organized as follows. In Section 2, we shall give a brief overview of the proposed system needs and a description of the main concept of the application-specific system. Based on our analysis, we propose a scheme that adopts more than one routing algorithm at different gateway nodes and track two protocols (a *robust* one and a *traffic-aware* one). Scalability of robustness provides the opportunity to handle normal operation as well as an acceptable reaction level to emergency situations. In our approach, topology control is fully centralized and the central unit is responsible for network management. Section 3 shows routing considerations by taking three well-known wireless routing protocols into account. Related work subsection introduces that the basic idea of this system is partially mentioned by other researchers, however, never considered for indoor application-specific localization problems. Section 4 details some Chipcon CC1010EM hardware capabilities. We will then identify the challenges of wireless protocol engineering and clarify the differentiation between media access control and routing tasks. In the detailed system description we propose the use of a particular load-balanced traffic-aware mode and one modified flooding-based reliable mode routing protocol. In Section 5 we present simulation settings and results. Scenarios have been set up in OPNET 10.5. Underlying protocol layer models are provided by OPNET network simulation package. We compare the multiple protocol results to other single-protocol schemes using the same scenarios. Finally, we conclude the paper and envision some future research directions.

2. DESCRIPTION OF THE APPLICATION-SPECIFIC SYSTEM

In this hierarchical, cluster-based application-specific system, badges send their position information periodically to their cluster-head gateway units. Gateways also act as routers and propagate the information in a multi-hop manner towards a central authority. We differentiate between two zones around the CMS unit (Figure 2): Traffic-Aware-Mode Zone and Reliable-Mode Zone.

Zone 1 (*Traffic-Aware-Mode, or TAM Zone*) contains wireless router units that use a traffic-aware information routing protocol. These TAM nodes are expected to handle much more traffic than the units in Zone 2 (*Reliable-Mode, or RM Zone*). A Zone 1 unit can receive information from the outer Zone 2 units, from a different router in Zone 2, and from badges within its own antennas range. After receiving the information, it selects one of its neighbors and forwards the packet. Final destination of all information is the CMS station.

In the outer zone, RM routers concentrate more on collecting and aggregating badge location information. They also get packets from each other. After receiving the information, they send information to other Zone 1 and/or Zone 2 units.

Based on incoming traffic and location information of routers and badges in the system, CMS calculates optimal and suboptimal routes in Zone 1. CMS determines individual *routing tables* for each TAM router and then disseminates this information by sending special-purpose route control messages addressing TAM units only. When traffic and/or network topology parameters change so that these changes induce a more optimal routing in Zone 1, CMS recalculates and redistributes the routing tables. On the whole, the central station manages and regularly oversees routers in Zone 1.

In the proposed system, CMS is expected to have much more resources (memory, processing capacity, battery-level) than the independent TAM or RM units. The concept is that it may be a powerful laptop or desktop computer. CMS is capable of performing heuristic and deterministic calculations quickly in order to determine routes in Zone 1 based on topology and traffic information. An additional important function of CMS is that it can order a specific RM unit to change its role to TAM. This way it can scale and dynamically change the area of Zone 1. If needed, CMS can force a TAM router back to RM.

The system implements a "many-to-one"-type route selection concept. Since wireless communication parts of the units in this network have very limited computing resources, CMS must calculate each routing table for each TAM unit. A TAM router unit uses the table and some additional information from CMS to choose the next hop of the packet – to which of its neighbor it should send. Therefore TAM nodes do not maintain large routing tables of complete routes to different stations. They do not even have to monitor and modify routing table settings. They just have to follow the pre-set values and forward incoming packets to the neighbor specified by the table.

At RM nodes the most important issue is to forward the traffic reliably towards the border of Zones 1 and 2. For this purpose we need a robust protocol and the importance of traffic-awareness becomes secondary. *Flooding* is the most well-known robust protocol. In the case of flooding, the source node broadcasts its packet, and every station in the wireless neighborhood can receive. When a packet arrives at a node, it first checks whether it already passed this node or not – based on the stored ID numbers of previous packets. If no ID is found, it broadcasts the packet again and stores packet ID. Even if some losses occur because of the stochastic characteristics of the wireless medium, flooding still can ensure a very high level reliability[4]. The biggest drawback of pure flooding is that it may generate a huge amount of traffic *if* more and more badges show up and report positions in Zone 2. If no packets were lost in Zone 2, all edge-TAM routers at the border of Zones 1 and 2 should have received data packets of the same originator RM node. Multiplication of packets raises reliability level in Zone 2.

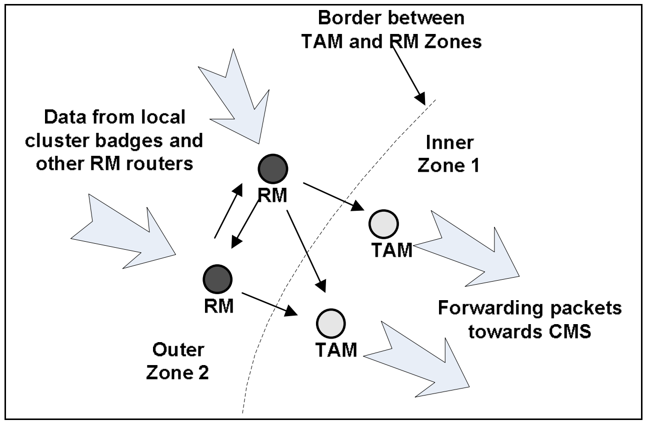

Figure 3: Virtual Border of TAM and RM Zones

3. ROUTING CONSIDERATIONS AND RELATED WORK

Routing in this application-specific system differs from those well-known peer-to-peer routing algorithms in wireless ad-hoc networks. Nevertheless CMS can use some aspects of these protocols.

3.1. Three typical wireless ad-hoc routing protocols

Typical wireless ad-hoc routing protocols have been developed mainly for any-to-any communications. In this subsection we introduce three well-known techniques: *Dynamic Source Routing* (DSR[5]), *Destination-Sequenced Distance Vector* (DSDV[6]) and *Ad Hoc On-demand Distant Vector* (AODV[7]) protocols.

At source routing, information source nodes determine the route of the packets throughout the network. DSR uses *route discovery* and *route maintenance* algorithms. When a source does not have a route for a desired destination, it launches route discovery mechanism. It is a procedure by which a source discovers a route to a destination. A ROUTE REQUEST (RREQ) packet is broadcasted and then it is flooded across the network. RREQ contains source ID of the originator unit, destination ID and a routing path record that stores the sequence of stations passed or hops taken. By the use of sequence numbers we prevent duplication of RREQs. The request is answered by a ROUTE REPLY (RREP) packet either by the final destination or an intermediate node that has information about an existing route towards destination. In order to limit the number of requests within an acceptable level, each node allocates memory to maintain routes that have been learned directly or by overhearing from passing traffic. Route maintenance monitors the state of the available routes and informs the source about any errors. When a link becomes unavailable, the detecting host sends back a ROUTE ERROR (RERR) packet to the source indicating that all the routes containing that link must be removed from the memory. In many applications, network routes have been identified in a full or partial graph structure model of the network[8].

In contrast to DSR, DSDV is of a programmed or proactive-type protocol, where the routing tables of a node track all reachable destinations, the hop count to reach particular destinations and the next hop (including defaults for unknown destinations). A node exchanges its routing information with its wireless neighbors periodically or whenever there is a change in the topology. Update packets contain the full routing table or only the elements that have been changed since the last update. Among several other parameters[9] the reception of a packet with an unknown destination sequence number may induce updates.

Designers of AODV intended to take full advantages of the previous two. They chose on-demand behavior from DSR and combined that with the use of hop-by-hop routing from DSDV. Similarly to DSR, routes have been explored via a route discovery procedure. When a node receives an RREQ, it looks up its table to see if there is information about a route towards destination. If a route is found, information is sent back in a RREP packet. If no information is found, the hop counter is incremented and the station broadcasts the RREP again. As a RREQ propagates through the network, a *reverse path* is being set up and sent back to the originator of the request. An important addition in AODV is the use of timers to expire routes that have not been used recently. AODV provides a wider propagation of RERRs than DSR, it uses a per destination predecessor list at each node. Typical AODV parameters include the number of request retries, durations of active route timeout and time to hold packets awaiting routes.

3.2. Related work

Investigating the many-to-one routing scheme in general, Bajcsy et al[10] indicated that an explicit, global coordination of the communication among router units was plausible in a static system. This can be done at the beginning of the data gathering process, just after the router units have been disseminated and initialized. Such a scheme requires extensive computation and processing at the centralized station, the gathering of topological information and the dissemination of control information. However, this solution is static and cannot be extended to take into account frequent topological changes. In our investigation we assume that TAM routers are more likely not to change their position once deployed and approved to traffic-aware mode by CMS. Therefore among these router units, a totally centralized coordination and organization by a powerful CMS is possible and highly desired. From this point of view, the major concept of AODV does not apply, because this protocol was originally designed for fast-changing wireless topologies.

For calculation of TAM routes, CMS creates the virtual wireless connection *graph* such that CMS and routers are represented by vertices and there is an edge between two nodes if and only if a wireless link exists between them. In this CMS-rooted graph, we are looking for a spanning *routing tree*. Based on this tree each node knows the next hop node to which a packet should be forwarded in order to reach CMS finally[11]. In our system, CMS calculates the tree and then individually informs the routers where to route when a packet incomes from a given wireless neighbor. In other systems the process of creating this tree is similar to distance vector routing of DSDV: the parent node broadcasts its reachability and cost to the central station and its children recursively perform the same task[11], increasing the cost by some non-negative amount at each step. Finally this results in each node to know the next hop along the smallest cost path to the base station. In our system, however, we assume that CMS has the information about the traffic generation pattern of each TAM node. Hence there is a need to extend the distance vector calculation method using additional traffic generation information of every individual TAM router.

Marco et al[12] showed that c_N, the many-to-one capacity of a static wireless sensor network of sufficiently large size N, is bounded by $\Theta(1/N)$ bits/sensor/slot, meanwhile the number of bits per slot that the collector unit can receive is bounded by a certain bound of W bits per slot. Data-oriented many-to-one communication results in non-uniform power drainage and packet loss in the network due to increased network usage and interference around the sink. Similarly, in our proposed application-specific system CMS represents the wireless bottleneck since it is the major data collector.

Das et al described DSR, DSDV and AODV routing protocols performance in a many-to-one ad hoc mobile communication system[13]. They found, that in a special ad-hoc sensing network, DSR had the lowest communication overhead at all mobility because DSR could reuse the routes that other nodes discovered towards the sink. Since AODV is on-demand in contrast to DSDV which is proactive, it has a low communication overhead in a static network. In a static network, AODV and DSR have close to zero overhead meanwhile DSDV incurs a constant overhead for all values of mobility.

4. MULTIPLE PROTOCOL DESIGN CONSIDERATIONS

We first introduce the design constraints that have been considered when constructing a multiple (two) protocol routing scheme in the network, in particular the most important limitations on hardware, stack of the protocol architecture and characteristics of the proposed system. We then proceed to describe the details of the selected TAM and RM zone protocols.

4.1. Hardware

In this application-specific system, the routing protocol is constrained by some special hardware parameters of a communication part of a unit. Both badges and routers (including CMS) have the same physical communications characteristics represented by Chipcon CC1010 Evaluation Module chips[3] (Figure 4).

Figure 4: Chipcon CC1010EM with Antenna

Chips are empowered with a 3-3.3 V input voltage provided by 2 AA batteries. The most important communication parameters include:

- ◊ Transceiver characteristics:
  - o The antenna range is 10-15 meters (indoor);
  - o Raw data bit rate is 76.8 Kbps, chip uses NRZ or Manchester encoding[4];
  - o The antenna can operate in the 300MHz-1000MHz frequency range. Typical center frequency is 868/916 MHz (900 MHz ISM band);
- ◊ Capacity of the available flash memory is 32Kbytes, plus 2048 + 128 bytes SRAM that is also available for fast operations.

4.2. Protocol Architecture

In the classical ISO OSI protocol model, network layer (Layer 3) is responsible for construction and maintenance of the routing structure (Figure 5). The proposed routing scheme controls the routes in a centralized manner, and hence operates in the network layer.

Network	**Layer 3**
Data Link **MAC Sublayer**	**Layer 2**
Physical	**Layer 1**

Figure 5: Classical Protocol Stack Model

Layered investigation of the communication protocol allows us to handle different layer functionalities separately from each other. This way, developers can implement and test different code modules independently.

Medium access rules determine which unit, at which frequency and when is allowed to radiate its frames. Numerous types of media access control (MAC) protocols have been proposed so far. The majority of wireless sensor network MAC investigations concentrate on energy-savings and power-aware operations, such as S-MAC[15] and B-MAC[16] etc. Others consider various modifications of Time Division Multiple Access (TDMA) and/or Frequency Division Multiple Access (FDMA), for example SS-TDMA[17] and T-MAC[18] etc. In cluster-based systems, different MAC protocols can be used for intra-cluster (Badge-Router interface) and inter-cluster (Router-Router interface) communications. However, some schemes propose no distinction and only one MAC principle is used for both (GANGS protocol[19]). Our intention is that Layer 3 routing algorithm works for all types of MAC protocols.

Although we acknowledge that both data link and physical layer characteristics affect the protocol's overall performance, in this initial study, we shall focus on routing issues for this application-specific sensor wireless location system.

4.3. Characterization of Multiple Routing in the Application-specific System

The idea to adopt multiple routing protocols in a many-to-one architecture arises when strict limitations of devices and special-purpose features lead to the need for an application-specific solution. Additionally, in different regions of the network where different traffic patterns are expected, corresponding different strategies would fulfill the requirements. In an application-specific, indoor wireless localization system, we assume that a localization algorithm exists such that each entity is able to determine its relative position based on beacon signals. Our work focuses on the information propagation of different nodes' location information. In the two-level hierarchical system, badges attached to people and devices in an indoor environment choose gateway units in their wireless neighborhood and periodically report about their location. A gateway unit acts as a cluster-head and receives data from one or more badges within its local cluster area (intra-cluster communication, badge-router interface). A gateway unit has a dual functionality. It also acts as a router and can receive and forward information from/to other gateway-routers (inter-cluster communication, router-router interface). Flows of packets finally reach CMS that stores, analyzes, and displays data. Having powerful energy and processing resources, CMS can calculate routes as well as send those to selected nodes.

As packets approach CMS's neighborhood, traffic becomes more and more concentrated. The closer a router is to the CMS, the higher the probability that it needs to forward more traffic. Therefore, a wisely assigned Traffic-Aware Mode (TAM) Zone around CMS should adapt a traffic-aware many-to-one information routing concept. TAM Zone routers are to be selected and managed directly by the central station.

Routers far from CMS are expected to have less passing-through information, since the many-to-one scheme pushes data towards the central authority. In a wireless indoor localization system, where reliable transfer is the primary issue, we should select a different routing protocol than that of TAM Zone routers located closer to CMS. This Reliable Mode routing algorithm increases reliability of the outer zone by increasing redundancy. Redundancy can be increased by generating more packets and propagating the same information using multiple routes. The multiple-route operation ends when packets reach closer to CMS and enter the TAM Zone. In summary, in the outer zone, we achieve more robustness and a higher-level overall reliability at the expenses of more traffic.

By default, each router starts its operation in Reliability Mode (RM). It localizes itself and starts collecting information from neighboring badges and routers. RM algorithm tells which incoming packet it needs to store and forward. As traffic load increases, RM operation continues until it receives a control message from CMS indicating a change in its status to TAM and with where-to-route information parameters for TAM.

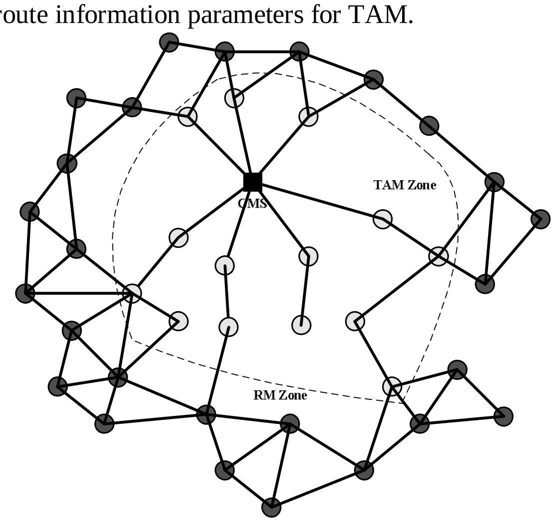

Figure 6: Routing Tree in TAM Zone

4.4. Traffic-Aware Many-to-one Routing

CMS identifies all routers in the system and assigns a w_i weight to each router based on its expected incoming traffic load that it needs to forward. It also checks the information load of each router and based on a *threshold* value that will decide which router – if any – should act in a TAM. CMS then sets up the wireless connection graph for TAM Zone and calculates an *optimal* multi-hop routing tree. Chipcon CC1010EMs are capable of communicating at multiple frequencies. Therefore by the use of an FDMA/TDMA-based MAC, we consider no interference and assume that neither *hidden terminal* nor *exposed terminal* problems[4] occur. Having only one omni-directional antenna, a router can not send and receive at the same time. Since we assume that routers have less constraints on battery, energy-level of units are *not* taken into account. Nevertheless, the protocol should pay attention to memory and packet queue size constraints. For reliability reasons, no packets are allowed to be lost in the system. Packets have been handled in the queue following First Come First Served (FCFS) rule.

Finding optimal routes to a vertex in a given communication graph when traffic load weights are given for each vertex has been proven to be an NP-hard problem[20, 21]. However, several heuristics may apply[21] to such problem In order to meet both traffic-awareness and reliability requirements, we use a rather simple *load-balancing* TAM route computing method at CMS. However, this method is extremely computationally intensive for larger networks.

For TAM route calculations, we group TAM routers based on how far they are from CMS, e.g. how many hops a packet takes at least to reach CMS from a particular router unit. Groups usually represent layers or tiers around CMS. The first layer contains routers in the one-hop neighborhood, and the n^{th} layer includes routers in an n-hop distance. Then we create the set of all possible trees rooted by CMS in the given graph. The next step is to calculate one-by-one how much traffic a router should handle. We start the computations in the outermost layer and when ready we continue the process in layers closer to CMS until we finally reach CMS.

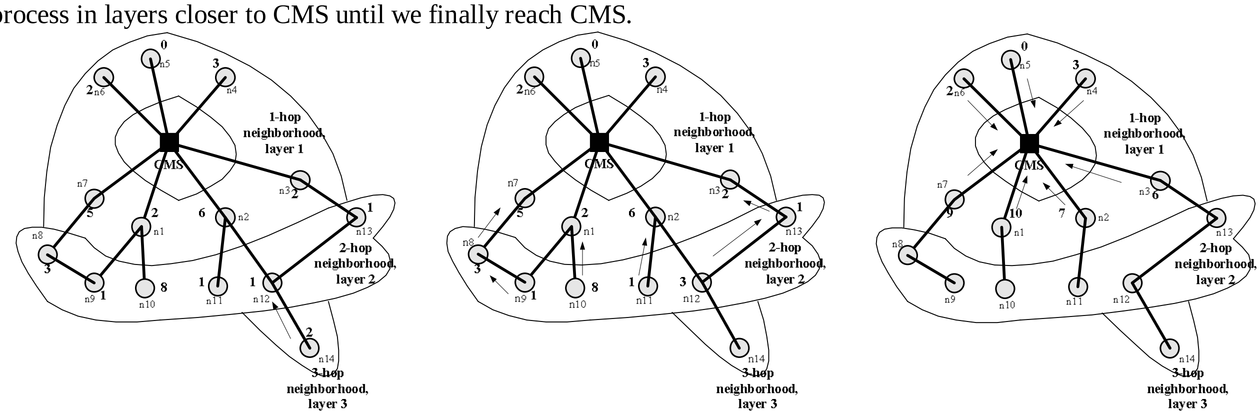

Figure 7: Routing in TAM Zone

The n^{th} layer is defined to be a *load-balanced* layer if total traffic load is equal for each router in that layer. Load of the i^{th} router when *load-balanced*:

$$load_{i,balanced} = \frac{TL}{r};$$

where r is the number of routers in layer n and TL is the total incoming traffic from badges and neighboring layers.

We calculate the load-balancing factor in the n^{th} layer as:

$$f_{n,LB} = \sum_{i=1}^{r} \left| \frac{TL}{r} - load_i \right|;$$

The closer this value to zero is, the more load-balanced the n^{th} layer is.

We expect that traffic is more concentrated closer to CMS. Therefore we select those tree or trees out of the set of possible trees that have the least $f_{1,LB}$ value. If more trees exist then we calculate $f_{2,LB}$ for all the selected trees and pick those with the least $f_{2,LB}$ value. We continue the process until we get one tree or reach the outermost layer. In the latter case, if more than one trees pop up we pick one of them. The resulting tree of this process will be the selected route tree in TAM zone.

After the calculation of the routes, CMS creates individual control packets for each TAM router indicating where-to-route information. Control packets are flooded through TAM zone.

4.5. Reliable Mode Routing

For RM zone routing, our application-specific system uses a modified version of flooding. Flooding is a simple and robust method that provides the desired advanced level of reliability in the outer zone by the multiplication of packets. One major problem with flooding is the amount of the traffic. However, modified flooding schemes can limit the amount of generated traffic:

1. Geographic Routing scheme[21]: an RM router receiving a broadcast packet from its neighbor radiates that again if – by knowing the position of its neighbor as well – its position is relatively closer to CMS. If it is not closer to CMS, it will drop the packet.
2. HTL (Hop-To-Live) counter: when first broadcasted each packet is initialized with an HTL value, that decreases by one after every further broadcast. Packets with zero HTL are dropped by RM routers.

5. SIMULATIONS, SCENARIOS, SETTINGS

We simulated the performance of the proposed multi-protocol scheme using OPNET Simulator[24]. The goal of the simulation is to demonstrate the advantages of both TAM and RM modes designed for this application-specific system. Note that adaptive selection of TAM and RM operations for any node by CMS has not yet been implemented. Roles of individual routers have been set manually. We have extended and modified existing station models in OPNET in order to facilitate most important characteristics of Chipcon CC1010 EM, including encoding type, raw data bit rate (76.8 Kbps), antenna range, frequency (900 MHz ISM band) and packet queue size (memory available for storing packets before sending). The localization algorithm requires approximately 16 Kbytes of memory, meanwhile we assume that the majority of the remaining 16 Kbytes is needed for Layer 1 and Layer 2 (MAC) and routing protocol code implementations. We reserve roughly 1 Kbytes for temporary packet queue purposes. Considering the packet size of about 100 bytes, this will result in 10 packets capacity for one buffer.

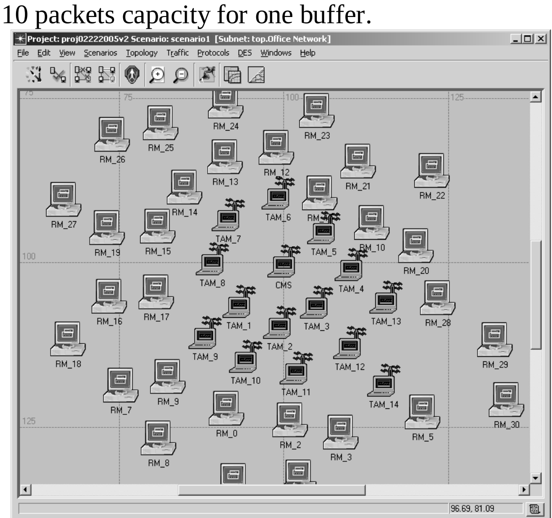

Figure 8: Scenario - OPNET Simulation Environment

In our test network, badge location reports are handled as generated pre-set on-off type traffic sources assigned to gateway-routers. Report packages have been injected into the network periodically. Routers have been handled as fixed units, no mobility pattern have been set. 15 out of 30 RM routers and 8 out of 13 TAM routers generated traffic in the system.

We compared the proposed protocols performance to the built-in on-demand DSR protocols performance in the same structure.

5.1. Results

The throughput of the system is interpreted as *information throughput*. In the RM zone, packets are flooded. However, those packets carry redundant information. As traffic load increases (packet generation period decreases or number of injected packets increases), average queue size of router units become longer. We observed, that fewer packets were dropped when we used TAM routing in TAM Zone (Figure 9). Note, that the total number of packets in the system increased when we used the multi-protocol scheme due to RM Zone packet multiplications.

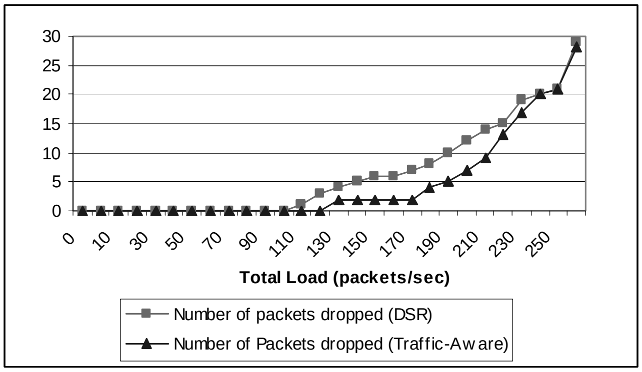

Figure 9: Packet Drops in TAM Zone

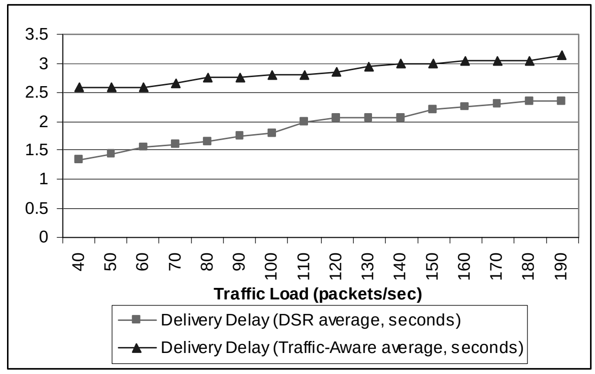

Figure 10: Delivery Delay (s)

In order to measure robustness level, we intentionally inactivated single stations during the simulation runs at a given probability. Modified flooding showed better robustness characteristics as we expected for lower loads. In case of DSR, when a router goes down, packet under transmission and all the packets in the queue became lost. In RM Zone, even if packets are lost due to outages, information can still be recovered at CMS from packet clones forwarded by other RM routers. Note that the goal is to emphasize the gain in our proposed application-specific system. Hence we do not track direct quantitative results, we rather concentrate on comparative analysis.

Delay of packets in TAM Zone is expected to be worse than the delay induced by the use of DSR (Figure 10). The layer-based traffic-aware scheme assigns routes in a load-balanced way. Traffic is expected to be more distributed in a layer. Therefore, by the use of TAM routing, we earn some more reliability and flexibility in TAM Zone, at the expense of increased latency.

6. CONCLUSIONS, FUTURE WORK

In this paper we proposed the use of multiple protocols in application-specific wireless indoor localization systems. Units of the system determine their positions based on a pre-assumed localization method. The hierarchical system is cluster-based. Gateways collect from neighboring badges the location report information. Gateways act as routers as well; they propagate data towards a central authority in a multi-hop manner.

We introduced a two-protocol scheme with a Traffic-Aware Mode (TAM) inner zone and Reliable Mode (RM) outer zone operations. In this many-to-one communications system, Central Monitoring Station is responsible for traffic monitoring, displaying and analyses in order to tailor TAM zone and hop-by-hop routes. TAM routers receive where-to-route next hop control information from CMS. For RM zone routers, a robust, modified flooding algorithm is proposed. For hardware characteristics, we take parameters of Chipcon CC1010EM chips into account. At simulation settings, we defined TAM and RM zones manually. The central decision about a change of a routers status from RM to TAM and vice versa has not been fully implemented yet. Simulation results showed that reliability level in the outer zone and throughput under special circumstances in the inner zone have been improved comparing to the DSR protocol. This performance was achieved by using traffic-awareness information at route decisions and at the expense of increasing delay of packets in the system.

Notice that this study mainly concentrated on two-dimensional networking. However, the proposed scheme can be extended to 3-D (levels, floors in buildings). Moreover, the multi-protocol scheme may include more than two protocols in large networks. Considering the accuracy of the localization method, futher improvement can be achieved by sending only the significant difference to the last reported location of a badge so as to reduce the number of packets to be transmitted.

Assuming that people and devices show up more likely at the edge of the network and usually do not move fast, CMS can predict well traffic fluctuations and changes. In the near future we plan to program and evaluate our scheme into a pilot network containing CC1010EM modules.

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