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Cluster Message Criticality Level Based ZigBee Routing for Smart Energy Home Area Networks

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***Abstract*—Advanced Metering Infrastructure (AMI) and Demand Response (DR) are the two main objectives of smart grid require active participations of consumers to enhance the quality as well as reliability of power dispatch. To achieve this, a two-way communication system is needed for acquiring real-time home information to support dynamic price, bill, control from the utility and export of surplus power. It is envisaged by smart energy profile based home area networks (SE-HAN), deployed using zigbee devices at the residential levels. In SE-HAN, certain services of AMI and DR are realized by transacting the clusters messages between the intended SE devices such as smart meters and smart appliances. For zigbee network routing, cluster message criticality level based routing(CMCLZBR) is proposed that improves the performance of SE services by selecting an appropriate routing (AODV/ZHTR). Further, zigbee neighbor table shortcut tree routing (ZNSTR) is proposed to include as one more routing option to achieve near optimal path if entries of neighbor nodes in the table. Performance evaluation shows that ZNSTR outperforms ZHTR in all the network conditions as well as exploits limited routing overhead with AODV.**

Keywords--Smart Grid, Advanced Metering Infrastructure, Demand Response, Cluster Message Criticality, ZigBee, Neighbor table, Shortcut tree routing, Home Area Networks.

I. INTRODUCTION

In the twenty-first century electrical power industry is experiencing major challenges. Currently many technologies and solutions are available to make the electrical industry so smart [1], [2]. The current electrical grid is envisaged to be evolved into next-generation "Smart Grid" by an automated system with improved communication. Great advancements in energy efficiency, short recovery times and isolation of electrical failures are more benefits to customers and utilities. This is anticipated by modifying the way energy is consumed by residential customers. For that, Advanced Metering Infrastructure (AMI) and Demand Response (DR) are introduced in Smart Energy (SE) system to collect real-time data and compute energy consumption for dynamic pricing, billing, statistical purposes, system control and load control [3]. At the residential levels, a communication system is required to perform the key functions of AMI and DR. This is envisaged by smart energy Home Area Networks (SE-HANs) that act as the last hop of Smart Grid networks [4].

The conception of SE-HAN visualizes that the network from each individual smart appliance to a concentrator shall be a one-hop network. The concentrator is usually referred as Smart Meter that shall be the in charge of acquiring the home information and transmitting it to the utilities. Generally, smart meters furnished with at least two network interfaces-one or more for internal communication and one for external communication. The internal one interconnects all home appliances and external one interconnects Smart Meter to the Neighborhood Area Network (NAN).

The possible modes of communication to be used in HAN are Power Line Communication (PLC) and Wireless. Available network standards are X-10, PLC-BUS and HomePlug for PLC and for wireless mode, Bluetooth, WiFi and ZigBee that best meet HAN requirements [5]. The main reason for choosing PLC that it does not require additional infrastructure, uses existing in-home power line network to transmit information. In contrast, wireless network technologies require basic infrastructure and no need of cabling, where the devices can be included or isolated easily to access common wireless-based networks. Smart Grid Forum arrived with a consensus that the suitable communication mode is wireless and technology is ZigBee for SE-HANs [6], [7].

ZigBee is a wireless personal area network (WPAN) standard targets low data rate, low power, cost-effective, less complexity, reliable and scalable [8]. This technology focuses on short range wireless links and operates on the same 2.4 GHz ISM band as WiFi, Bluetooth and WiMax [9]. In order to avoid mutual interference, ZigBee sets wireless device transmission range as 10 to 75 meters depend on the network environment conditions [10]. Network configuration, node addressing, packet routing and network management are made possible by ZigBee network layer [11]. It can support up to 64,000 nodes in a network by employing a routing protocol called ZigBee routing (ZBR) that selects either AODV or ZigBee hierarchical tree routing (ZHTR).

In AODV, communication between each pair requires on-demand route discovery so that the memory consumption and the discovery overhead increase with the number of traffic sessions. In ZHTR, since each node is assigned with hierarchical tree address, any source node can transmit a packet to any destination with null route discovery overheads. So, that ZHTR is a promising routing protocol for resource limited devices deployed applications such as smart grid networks [12]. Nevertheless, ZHTR routes the packets along tree nodes to the destination despite the destination is located nearby. In order to provide the optimal routing path, ZigBee Neighbor-table Shortcut Tree Routing (ZNSTR) is proposed to improve the path efficiency by adding 1-hop neighbor knowledge. ZNSTR focuses the neighbor nodes only to make shortcut in the tree routing path. Further, this paper proposes a Cluster Message Criticality Level based ZigBee Routing (CMCLZBR) to select an appropriate routing (AODV/ZHTR/ZNSTR) based on criticality levels of cluster message for improving the performances of SE services.

This paper organized as follows: Section II proposes CMCLZBR for SE-HANs. Section III proposes ZNSTR to solve the problems of ZHTR. Section IV evaluates the comparative performance of AODV, ZHTR and ZNSTR by differentiating the network conditions such as ZigBee constraints, network density and network traffic. This paper concludes in Section V.

II. ZIGBEE ROUTING IN SE-HAN

ZigBee Alliance has published a Smart Energy Profile (SEP) 2.0 in 2012 [13] and a Home Automation Profile in 2013 [14]. In these profiles, ZigBee protocol stack, different ZigBee smart energy devices (ZSEDs), interfaces and messages are defined to be used in SE Networks. Obviously, home appliance is a physical device whereas ZSED is software entity that comes with two sets of functions. Set I, specific to SE and set II, specific to ZigBee communication. With help of a ZSED, a physical appliance would become smart. This section presents a suitable communication infrastructure and the role of clusters to perform the functions of AMI and DR.

A. Smart Energy Home Area Networks

SEP has introduced a network infrastructure, called *SE Network with Utility and Customer Sectors* [15] shown in Fig. 1 to provide high degree of consumers' active participation by incorporating the SE-HANs at the residential levels. It is formed by a set of different purpose ZSEDs that are *Energy Service Portal* (ESP), *Metering Device*, *In-Premise Display* (IPD), *Programmable Communicating Thermostat* (PCT), *Load Control Device*, *Pre-payment Terminal Display*, *Range Extenders* and *Smart Appliances*.

In order to extend the SE network range and reduce network power consumption, each ZSED is configured either coordinator/router/end device. Router and coordinator must be enabled as full function device (FFD) whereas end device as reduced function device (RFD). Since end device is RFD, they have limited functionalities, require limited memory and capable to interact with appliances and parent nodes only. An ESP interconnects the Utility Private SE-HAN with the Utility via backhaul network. Moreover, ESP will be the in charge of coordinator that set up the network, aware of all its constituent nodes and acts as a repository for security keys.

Furthermore, operating modes of ZSED, beacon and non-beacon, greatly impact on network power consumption by providing two different data traffic. In beacon mode, periodical beacons of coordinator wake up routers while the other nodes check whether any beacons if not then nodes and

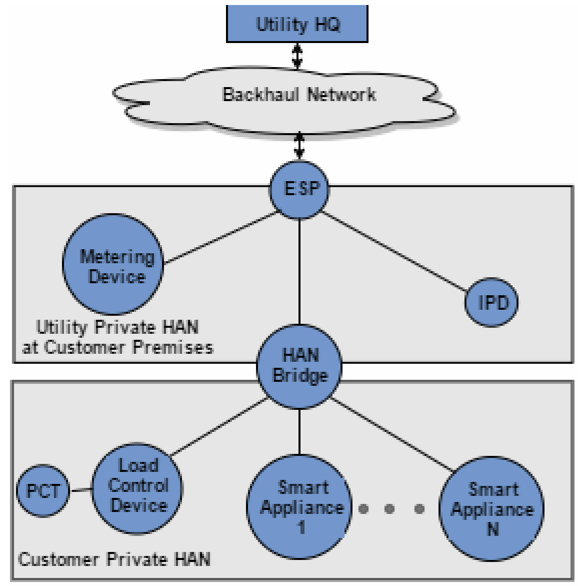

Fig. 1 SE Network with Utility and Customer Sectors

coordinator go back to sleep because of guaranteed time slots. In non-beacon mode, receivers of coordinator and routers always active because any node can wake up and talk to it, so that this mode requires a robust power supply and uses more energy.

B. An Example of SE-HAN Solution

The NXP has released user guides such as ZigBee Pro Smart Energy API [15], ZigBee pro stack [16], SDK Installation [17], JenOS [18] and ZigBee Cluster Library [19] to guide the SE system developers for developing the JN51xx wireless microcontroller based SE-HAN Solution. NXP guides and SDK are available in www.nxp.com/jennic at free of cost. This solution employs JenOS, NXP ZigBee Pro APIs and SE clusters altogether. APIs comprise core-resources, cluster-specific resources and required SE functions such as API initialization, endpoint registration, read/write request to access cluster attributes from a remote ZSED, event handling and error handling. Moreover, SE-HAN solution comes into exist after executing the 5 phases of a development cycle. In phase 1 and 2, network parameters of nodes and resources of JenOS will be configured consecutively. In phase 3, codes for SE applications are developed to be used in nodes. Phase 4 produces binary format of SE applications using JN51xx compiler/linker. Phase 5 uses a flash programmer that loads the application binaries into flash memory on respective nodes.

C. Smart Energy Clusters

In the context of Smart Grid, ZSEDs are implemented with only 4 layered networks stack [20] shown in Fig. 2. In the top most layer, SE Application instantiates 240 application objects. Each object is associated with a unique endpoint that acts as the I/O ports. Further, each endpoint on a local ZSED can interact with every endpoint on a remote ZSED. To target

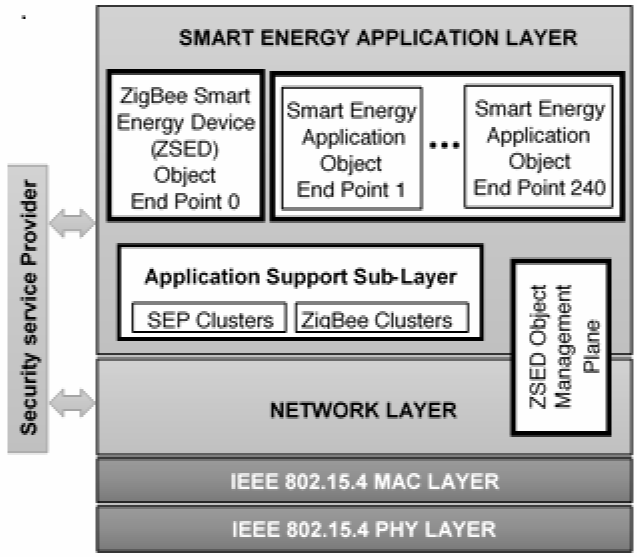

Fig. 2 ZigBee Network Protocol Stock

each endpoint, they are numbered from 1 to 240. Actually, SE Application utilizes the concept of clusters [15] to provide SE services. For that, different SE clusters are formed by inheriting the SEP clusters and ZigBee clusters. *Price*, *Message*, *Metering*, *Demand-Response*, *Load Control* and *Key Establishment* are the SEP clusters whereas *Time*, *Identify*, *Commissioning* and *OTA Upgrade* are the ZigBee clusters. Moreover, every SE service is established by transacting the values of different clusters' attributes among the intended ZSEDs. Section II-D depicts how the function of DR is carried out by means of SE cluster message transactions.

D. Demand Response

In order to minimize peak loads, Smart Grid includes a function called Demand Response (DR). It allows appliances to respond to dynamic condition on the grid and shifts load consumption in a real-time basis. ZSEDs involve in DR are ESP, PCT, Load Control Device, IPD and Smart Appliances. These ZSEDs use Demand Response and Load (DRLC) [15] clusters to receive load control requests from the utility and act upon them by controlling an attached appliance such as a heater or pump. Required DR services are established by means of client-server message transactions among the intended ZSEDs. Every ZSED participating in DR has one server-side DRLC cluster and four client-side DRLC clusters. Here, ESP used as server and four clients are PCT, Load Control Device, IPD and Smart Appliance. Since ESP is a server, it accepts the Load Control Events (LCEs) from the utility via the backhaul network while the clients receive LCEs forwarded by the server. In fact, LCEs start from the utility to schedule a temporary adjustment of consumption in appliances and the participations of appliances will be reported back to the utility via ESP. The LCEs' parameters are *LCE-ID*, *Target device class and enrolment group*, *Start-time*, *Duration*, *Criticality level*, *Required-adjustments*, *Randomization requirements* for start-time and end-time.

E. Cluster Message Criticality Levels

Like LCE, every SE function has number of its own events. During a particular SE function, results of events is shared among the participating ZSEDs in the form of messages. Apart from event oriented parameters, every SE event includes a parameter called criticality level. This parameter indicates the criticality level of particular cluster message being transmitted. The different criticality levels are used in an LCE as follows:

- *Green:* Indicates the significant contribution from non-green sources during the LCE – Participation is Voluntary.
- *Voluntary 1-6:* Utility defined load reduction levels 1 to 6 - intended to be used in a sequence of LCEs to gradually reduce the loads.
- *Service Disconnect:* Indicates an LCE for service disconnection, normally demanding the termination of all non-essential loads as defined by the utility. Participation is Mandatory.

F. ZigBee Routing Selection

In SE-HANs, the different criticality levels of cluster messages greatly impact on efficacy of a smart grid function [21]. For example, *Service Disconnect* in DR indicates the information contained in the LCE is Highly Critical Message (HCM) whereas other values of LCEs' criticality level are considered as Normal Message (NM). Similarly, every event of SE function has certain HCMs and NMs to be transacted among the intended ZSEDs. Further, every HCM should require a reliable routing protocol because it contains important data while NMs follow optimal routing path because it contains classic data.

When an SE application of ZSED ready to inject a message into SE-HAN, message packets are routed to destination by a suitable routing protocol reside in ZSEDs' network layer. AODV and ZHTR are the ZigBee compatible routing protocols for ZigBee deployed SE-HANs. In order to exploit the advantages of these two protocols, this paper

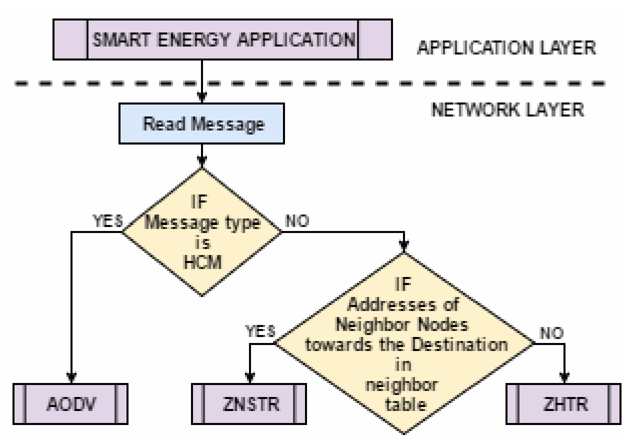

Fig. 3 Cluster Message Criticality Level based ZigBee Routing (CMCLZBR)

proposes ZNSTR and it is depicted in section III. In this section a routing protocol selection strategy, CMCLZBR is proposed and its objective is to select either AODV/ZNSTR/ZHTR depending on the criticality levels of cluster messages. This routing strategy routes the message packets of SE clusters to the intended ZSEDs.

Fig. 3 envisions the function of CMCLZBR. Its sequential steps are follows: First it reads a message when an SE application of ZSED is ready to inject a message into the network; Next, it examines the criticality level of that message; If a HCM competes for routing, then it selects AODV; Otherwise, if addresses of neighbor nodes towards the destination present in neighbor table, then it selects ZNSTR; Otherwise it follows ZHTR. That is to say, CMCLZBR employs either ZNSTR or ZHTR when a NM is competing for routing. This routing protocol selection strategy improves the reliability of SE function. Section IV presents the routing performances of routing protocols that are employed in CMCLZBR.

III. ZIGBEE NEIGHBOR TABLE SHORTCUT ROUTING

ZHTR is developed for resource-limited ZigBee devices to select multi-hop path without accompanying a route discovery process. It employs hierarchical address method [22] that assigns a unique address to each node using tree parameters L_m*(nwkMaxDepth)*, R_m*(nwkMaxRouters) and* C_m*(nwkMaxChildren)*. At the tree level *d*, each router node assigns address space and the size of address space is determined by *Cskip(d)* in (1), its value must be equal to $R_m \cdot Cskip(d+1) + (C_m - R_m) + 1$ for covering the address spaces of its router-capable children and end devices. A_k in (2) and A_n in (3) computes the address for each k^{th} router-capable child and n^{th} end device respectively. As the tree level increases, address space is split recursively and pre-allocates the available network address space at each tree level.

$$Cskip(d) = \begin{cases} 1 + C_m \cdot (L_m - d - 1), & if\ R_m = 1, \\ \dfrac{1 + C_m - R_m - C_m \cdot R_m^{\,L_m - d - 1}}{1 - R_m}, & otherwise \end{cases} \quad (1)$$

$$A_k = A_{parent} + Cskip(d) \cdot (k-1) + 1 \qquad (1 \le k \le R_m), \quad (2)$$

$$A_n = A_{parent} + Cskip(d) \cdot R_m + n \qquad (1 \le n \le C_m - R_m) \quad (3)$$

$$A_k < A_n < (A_n + Cskip\ (d-1)) \quad (4)$$

By applying the condition (4) on address of particular node, ZHTR decides whether that node is descendant of other given nodes. For instance, node *n* is descendant of node *k* if their address satisfies (4).

A. Detour Problem of ZHTR

When the destination is descendant of source or intermediate node, ZHTR routes the message packets to one of its ancestors; otherwise, towards the root. This routing cause detour problem when a message packet is routed to destination via several hops despite the destination is within 2-hop communication range of the source. Further, tree root and the routers experience rigorous congestion as well as collision of packets because the packets from various nodes are forwarded through tree links that degrade the network performances.

Fig. 4 illustrates the two different detour cases of ZHTR. Irrespective of ZHTR, ZigBee applies a special rule to mitigate the detour case 1 shown in Fig. 4(a). This rule transmits the packets directly towards the destination *D1* from the source *S*. However, this rule cannot mitigate all detour cases of ZHTR. For instance, a detour case 2 shown in Fig. 4(b) that cannot be mitigated because the destination D_2 is away 2-hop distance from the source *S*.

In order to mitigate detour and congestion in ZigBee network, this section presents ZNSTR. Initially, it finds 1-hop neighbor nodes using link state mechanism and keeps them in a table. Then it selects one of the neighbor nodes as the next hop node that has least leftover hops to the destination. Finally, it transmits the packets to next hop node. If there is no neighbor in table, it follows ZHTR. For instance, in Fig. 4(c) ZNSTR calculates the hops leftover for the neighbor nodes N_1, N_2, N_3, N_4, N_5, N_6 of source *S* as 6*, 5, 4, 2, 3, 4* respectively, then it selects N_4 as next hop node to transmit a packet towards the destination D_2; Otherwise it follows ZHTR.

B. ZNSTR Algorithm

The main idea of ZNSTR is to determine the tree hops leftover from a source node to a destination by exploiting ZigBee hierarchical address structure. Fig. 5 depicts the algorithm of ZNSTR and Table I lists the definitions are used in ZNSTR. In the network layer of a source or an intermediate node, ZNSTR is employed to find optimal shortcut route. First ZNSTR calculates the level and address for given destination node. Then, for every neighbor entry n_k, it calculates the leftover tree hops from the n_k to the destination as well as

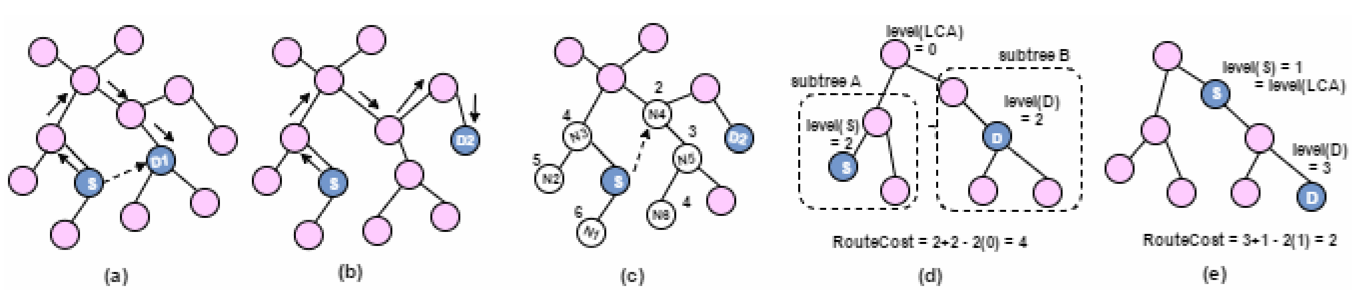

Fig. 4 (a) Detour problem: case 1 of ZHTR (b) Detour problem: case 2 of ZHTR (c) An example of ZNSTR
(d) Routing cost calculation: case 1 of ZNSTR (e) Routing cost calculation: case 2 of ZNSTR

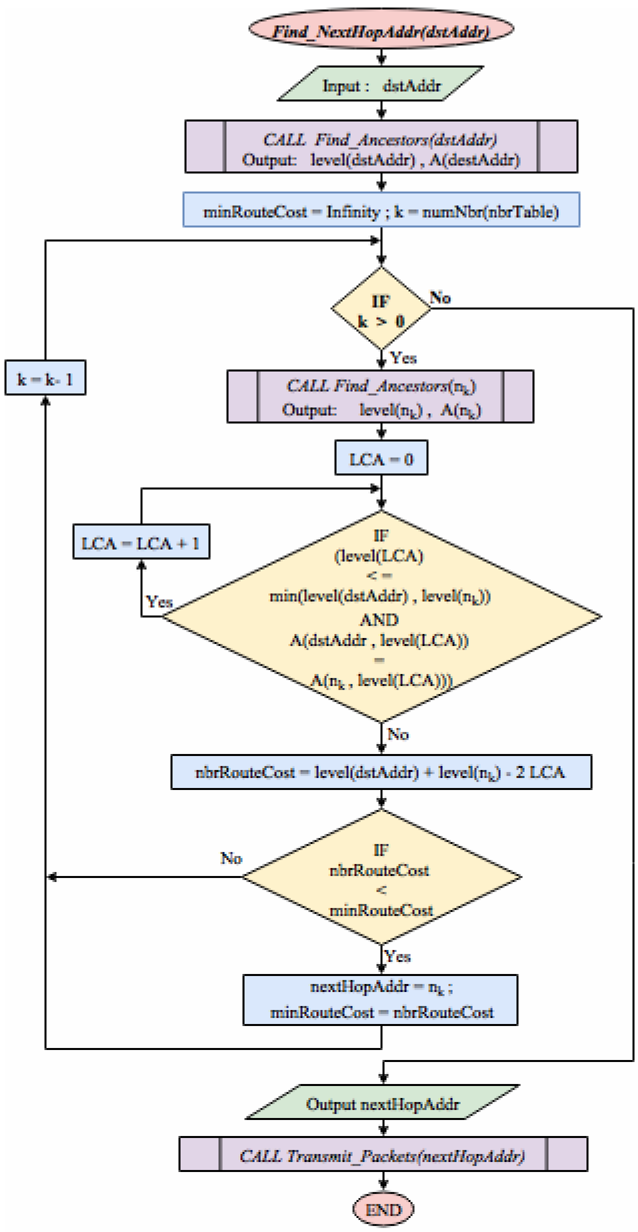

Fig. 5 Flowchart of ZigBee Neighbor Shortcut Tree Routing Algorithm

TABLE I
Definitions used in ZigBee Routing

Definition	**Meaning**
dstAddr	Address of destination
devAddr	Address of device
minRouteCost	Minimum Route Cost
nbrRouteCost	Route cost of neighbor node
nxtHopAddr	Address of next hop node
rIndex	Index value of router node
FunctionDefinition	**Purpose**
Cskip(d)	Returns size of address space at tree level d
level(u)	Returns the level of node
A(u)	Return address of a node
numNbr(nbrTable)	Returns number of neighbor nodes in table
LCA(S ,D)	Finds least common ancestor between *S* and *D*
Find_Ancestors(u)	Returns list of ancestors for a node

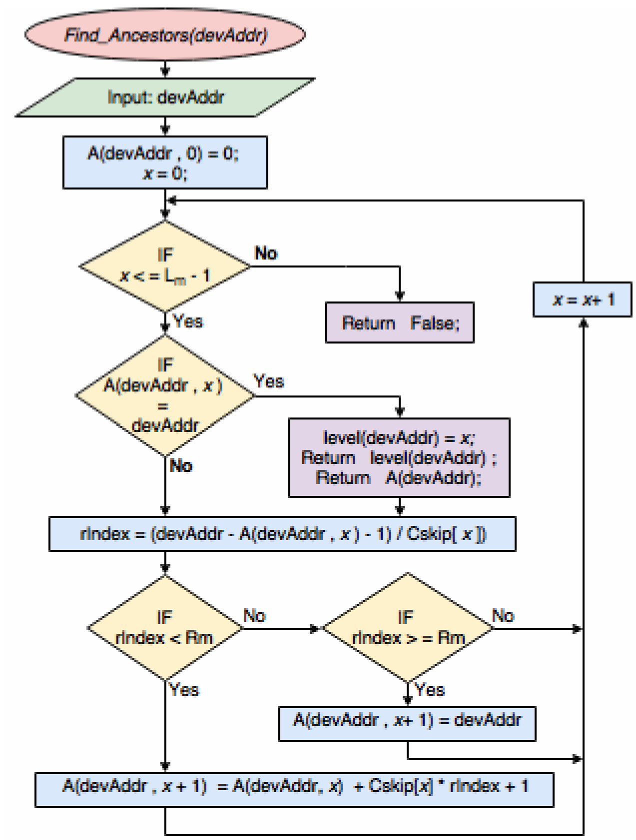

Fig. 6 Flowchart to ***Find_Ancestors*** at each Tree Level

nbrRouteCost using the functions *level(n_k)* and *level(LCA(n_k, dstAddr))*. After that, it selects a neighbor n_k as the next hop node that has the lowest leftover tree hops to the destination. Finally, it transmits a packet to the next hop node. If even single neighbor node is not in table, ZNSTR chooses the parent or one of children as the next hop node similar to ZHTR. So, the maximum limit of *minRouteCost* used in ZNSTR is the same as the routing cost by ZHTR.

The limitation of ZNSTR that it does not yield optimal routing path in all situations because the next hop node is selected depend on 1-hop knowledge. For example, in Fig. 4(c), the optimal path between S and D_2 is $S \rightarrow N_4 \rightarrow D_2$, but, it needs 2-hop neighbor knowledge to find N_5 is within 1-hop range of the D_2. Obviously, in high density network, keeping 2-hop neighbor knowledge offers high overhead [24], [25]; Therefore, this paper includes AODV in the performance evaluation and ZNSTR exhibits just 10-20 percent high hop distance compared to AODV regardless of network density. Thus, ZNSTR is considered as the best suit for resource constrained devices with respect to routing overhead and memory consumption.

Fig. 6 depicts the subroutine used in ZNSTR, namely *Find_Ancestors*. Since the network address of device is included in its address space of ancestor in lower tree levels, it finds the *rIndex*, which is the router capable child order k in (2). If *rIndex* is less than R_m, then *A(devAddr , i+1)* is router device and address is calculated using the addressing method for A_k in (2). A procedure begins from the root node that has the address 0, until the address of ancestor is same as the input parameter *devAddr*. By comparing the ancestors' addresses in each tree level, the addresses of the common ancestors between a source and a destination are determined. Intention of finding the address of devices' common ancestors is to calculate the routing cost between the given source and destination. This subroutine utilize two important functions namely *level(u)* and *LCA(S, D)* [23]. Fig. 4(d) and 4(e) illustrates two different cases for calculating routing cost between *S* and *D.* Always the source node *S* routes the packet up to the lowest common ancestor, *LCA(S, D),* through the parent nodes irrespective of *subtree A*. From the *LCA(S, D),* the packet is directed to the *subtree B* and traverse down via the child nodes to the destination. Since the routing hops from *S* to *D* through *LCA(S, D)*, the tree routing cost from *S* to *D* can be calculated by the equation (5).

$$level(S) + level(D) - 2 \cdot level\ (LCA(S, D)) \qquad (5)$$

The routing cost from *S* to *D* in case 1 shown in Fig. 4(d) is 4 because *S* and *D* are located in two sub-trees A and B of a tree whereas case 2 shown in Fig. 4(e) offers just 2 because *S* and *D* belong to *subtree B.*

IV. PERFORMANCE EVALUATION

This section presents the evaluation of routing performances and the impacts of network density and network traffic. Using the network simulator NS-2 [26], three different depth level ZigBee networks are configured with number of nodes *N = {41, 85, 145}*, maximum depth level $L_m = \{4, 6, 8\}$, number of routers R_m = {3, 5, 7} and $C_m = \{3, 5, 7\}$ as shown in Fig. 7. In order to evaluate the impact of network density, the fashion of node deployment shown in Fig 7(a) and 7(b) are also extended to the 2D surface 80mX80m as shown in Fig. 7(c). In all the network configurations, a PAN coordinator is placed at the center. For example, smart meter acts as the coordinator in ZigBee deployed SE-HANs. Table II shows the parameters used in simulations. To report the routing performances, ZNSTR is compared with ZHTR and AODV, because these three routing protocols are compatible to hierarchical address method. In general, ZigBee standard mandates the link state maintenance mechanism to make entries in neighbor table. The table entries are made and maintained using the link status message by a single hop broadcast at each *nwkLinkStatusPeriod* seconds. AODV use route discovery mechanism and link state maintenance mechanism to construct route discovery table and the table entries are made and maintained by route request (RREQ) packets in AODV. Both ZNSTR and ZHTR have no difference in routing overhead and memory consumption because of link state mechanism. In this regard, this evaluation showed interest in comparing ZNSTR with AODV.

A. *Impact of Network Density*

To study the network scalability features of routing protocols, the impact of network density with different traffic pattern is evaluated. Generally, traffic patterns are classified as

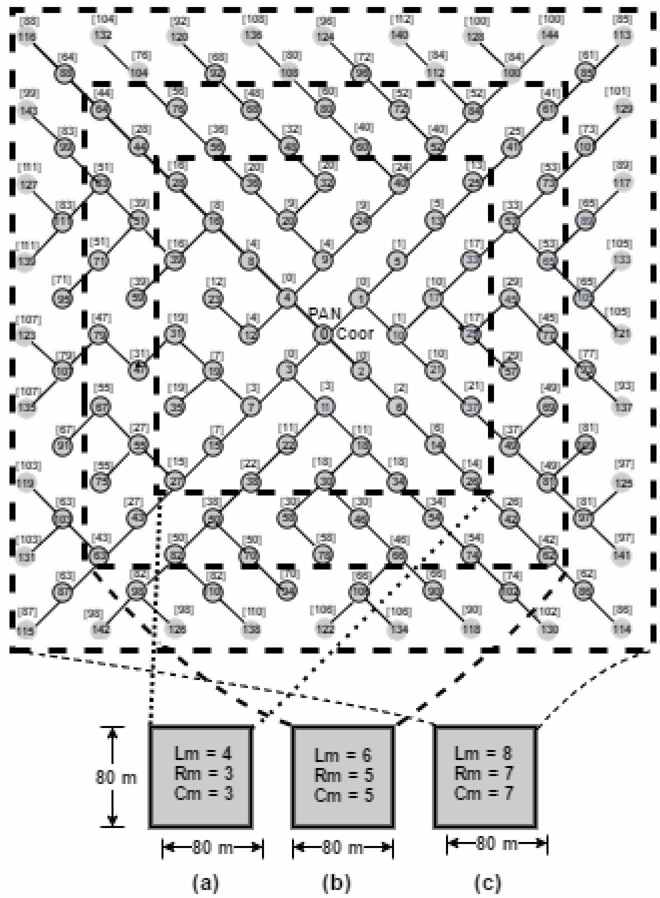

Fig. 7 Deployment of nodes and Network Configurations:
(a) 41 nodes (b) 85 nodes (c) 145 nodes

TABLE II
NS2 Simulation Parameters

Simulation Parameters	**Value**
Network Area	80m X 80m
Number of Nodes	41 / 85 / 145
Deployment Type	Random
Position of PAN Coordinator	Center
Number of Iterations	15
Number of Communication Pairs	40
IEEE 802.15.4 PHY/MAC Layer	
Propagation Model	Two-Ray Ground
Max. Rx range	25m
Channel Access Protocol	CSMA/CA slotted version
Max. Carrier Sensing range	30m
Interface Queue/Size	Priority Queue / 50
Beacon Order(BO)	3
Super Frame Order	3
Network Layer	
Protocols	ZNSTR/ZHTR/AODV
$L_m/R_m/C_m$	4/3/3, 6/5/5, 8/7/7
Traffic Type	Any-to-Any
Session-Packet Type	CBR
nwkLinkStatusPeriod	10s
Session-Packet Interval	1 packet/s
Session-Start / End Time	20-50 / 130-150 s
Simulation Time	150s
Association Duration	0-20s

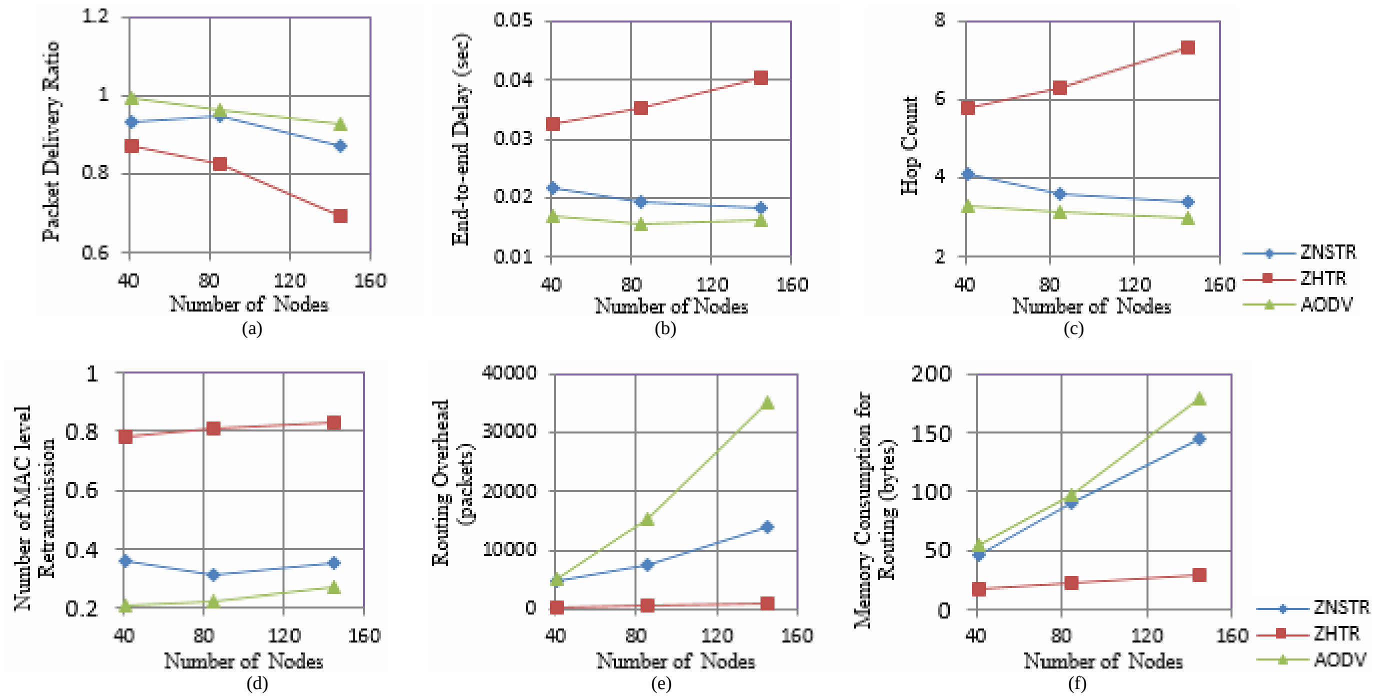

Fig. 8 Routing Performance and Overhead of the network density (a) Packet Delivery Ratio (b) End-to-End Delay (c) Hop count (d) Number of MAC level retransmission (e) Routing overhead (f) Memory consumption for routing

Any-to-Any traffic and Many-to-One traffic. Sources and destinations are chosen randomly in Any-to-Any pattern while Many-to-One sets a PAN coordinator as a sink and choose source randomly. Normally, we expect that Many–to–One traffic pattern has lower packet delivery ratio (PDR) than in Any-to-Any traffic pattern because of rigorous congestion toward the root of a tree. A fruitful evaluation which can be found from the Computer Society Digital Library at http://doi.ieeecomputersociety.org/10.1109/TPDS.2013.42, it destructs our expectation and proves that PDR drawn from any-to-any traffic is at least 10 percent lower than that of many-to-one traffic for all ZigBee compatible routing protocols [27], [28]. As well as it motivates us to conduct a high directive analysis on Any-to-Any traffic pattern with10 traffic sessions, if any improvement accomplished by ZNSTR then the results of Many-To-One traffic pattern can be derived easily. Certainly Any-to-Any traffic pattern offers more shortcut routing paths through participating nodes whereas the other traffic patterns offer shortcuts in rare occasions. Hence this paper imparts to analyze the routing performances of ZNSTR using Any-to-Any traffic pattern only.

B. Routing Performances

Number of successfully delivered packets is the key that determines the results of all routing performance metrics as shown in Fig. 8(a)-(d), and it excludes routing overhead and memory consumption. From Fig. 8(e) and 8(f), we assert that the number of control packets decides routing overhead whereas table size and entries determine the memory consumption. Note that all the results recorded in Fig.8(a)-(f) are the average of results drawn from 15 simulative instances.

Fig. 8(a) notices that PDR of ZHTR falls to 20 percent as the network density increases, since it has large hop count and routing path overlapping. Interestingly, ZNSTR and AODV produce highly distributed short routing paths with less interference and show higher PDR than in ZHTR. As the network density increases, AODV holds an attention even though it floods the route discovery packets before data packet transmissions cause more interference to degrade the PDR, still it exhibits higher PDR than ZHTR. In contrast, no routing overhead and no queuing delay in ZHTR that accomplish higher PDR by paying no attention to network density.

In Fig. 8(b), the end-to-end delay exhibits similar fashion with the hop count, since the hop distance between a source and a destination badly affects the end-to-end delay. Consequence of hop count, ZHTR registers long end-to-end delay about 0.0325-0.0405s. Without giving attention to node density variations, ZNSTR and AODV register consistent short end-to end delay 0.01967s and 0.01616s respectively.

Fig. 8(c) registers the average hop count between a source and a destination. ZHTR hop count shoot up from 5.8 to 7.3 hops, because the average tree level raise as the number of nodes grows, however both ZNSTR and AODV are unaffected since they yield the short routing paths irrespective of network topology. As the node density ascends, ZNSTR and AODV descend the average hop count from 4.1 to 3.4 hops and from 3.3 to 3.0 hops respectively. In contrast to ZHTR, the hop count of ZNSTR and AODV falls for the higher network density, since both routing protocols show high efficacy in determining the routing path from the increasing number of participating nodes. Note that ZNSTR has just 0.4 -0.8 more hop count than AODV despite the restriction of the local minimum based routing selection.

Fig. 8(d) depicts the average number of MAC level retransmissions. Every unsuccessful end-to-end communication initiates a MAC level retransmission due to channel access failure, packet collision, and missed acknowledgment. Number of MAC level retransmission is the level indicator that indicates the traffic congestion on the multi-hop paths and congestion avoidance capacity of each routing protocols in routing path selection. AODV achieves lower value of retransmission about 0.2 times consistently paying no attention to the network density variations. It means that AODV has 80 successful end-to-end communications from 100 attempts while ZNSTR has 66 successful end-to-end communications from 100 attempts. On contrary, ZHTR results 80 unsuccessful end-to-end communications from 100 attempts. As in the PDR case, the same reason that adversely influences the MAC level retransmissions.

Fig. 8(e) shows the routing overhead of routing protocols. As the network density increases, the routing overhead of AODV is increased exponentially due to flooding of RREQ (Route Request) packets into the entire network during the route discovery process. As well as route discovery packets and data packets are increasing proportional to the number of traffic sessions, collisions and retransmissions. In ZNSTR, routing overhead is determined by the control packets injected into the network during the link state maintenance process. Since ZigBee mandates the link state maintenance mechanism, ZHTR has same amount of routing overhead as ZNSTR. As the node density increases, routing overhead of ZNSTR increases linearly.

Fig. 8(f) exhibits the total memory consumption for the routing, where the entry sizes of neighbor table, routing table, and route discovery table are considered as 6, 5 and 9 bytes respectively. ZHTR occupies the less memory, because it only keeps the beacon transmitting neighbor nodes only. In contrast to ZHTR, ZNSTR and AODV consume more memory to have all 1-hop neighbor information derived from the link state maintenance mechanism. In addition, AODV requires additional memory to keep up the route discovery table and routing table. Inherently, AODV is the reactive routing protocol only when there is request on packet delivery which discovers the routing path; thus, both routing overhead and memory consumption of AODV adversely increases as much as the number of traffic sessions.

V. CONCLUSION

To enhance the overall SE network performances of ZigBee deployed SE network at the residential levels, this paper proposed CMCLZBR. This routing employs either AODV/ZHTR depend on the criticality levels of cluster messages. This paper reveals that detour path problem and traffic concentration problem of tree routing protocols are the sources for entire network performance degradation. To solve these problems, this paper proposes ZNSTR that uses neighbor table to find the optimal next hop node towards the destination. The network simulations exhibit that ZNSTR submerges ZHTR in routing performances respect to all the network conditions and outperforms AODV by removing the additional route discovery mechanism. Thus, ZNSTR can be used in resource constrained ZigBee applications that require small memory and high routing performances.

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