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Application Aware Energy Efficient Geographic Greedy Forwarding in Wireless Multimedia Sensor Networks

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Abstract—Finding maximum number of node-disjoint paths for transmission has always been a prime aim to achieve reliability, security, load balancing and improved performance. Finding paths that lead to maximum network lifetime is the other extreme that is desired. Algorithm that aims at one of the requirements tends to oppose the other. In this paper, we propose an Application Aware Energy Efficient Geographic Greedy Forwarding (AAEEGF) routing algorithm for Wireless Multimedia Sensor Networks (WMSNs) that is a trade- off between finding maximum number of node disjoint paths and finding paths with maximum network lifetime. AAEEGF takes into account both the requirements of real time multimedia transmission and the realistic characteristics of WMSNs. It finds list of node-disjoint routing paths with improved lifetime with path delays less than time constraint of the application. AAEEGF supports three features: (1) hole-bypassing, (2) explore maximum number of node disjoint path, and (3) lifetime improvement of paths, at the same time. AAEEGF is a pure geographic greedy forwarding routing algorithm and is an extension to Two-Phase geographic Greedy Forwarding (TPGF) [1]. Exploring paths in AAEEGF is time constraint dependent. All the paths obtained as a result have path delay less than time constraint of application. Unnecessary paths, whose end-to-end delays may exceed time constraint, are not formed, thereby making such nodes to be available for other useful path formation. This point allows more nodes to be available for AAEEGF to explore more routing paths, and enables AAEEGF to be different from many existing geographic routing algorithms like TPGF. AAEEGF improves lifetime of the found paths within the time constraint. Both theoretical analysis and simulation comparison in this paper indicate that AAEEGF is highly suitable for multimedia transmission in WMSNs.

Index Terms— node-disjoint path, NetTopo, TPGF, Wireless Mutimedia Sensor Networks

I. INTRODUCTION

Efficiently transmitting multimedia streams in Wireless Multimedia Sensor Networks (WMSNs) is a significant challenging issue, due to the limited transmission bandwidth and power resource of sensor nodes. Three recent surveys [2]-[4] on multimedia communication in WMSNs show that current existing protocols in both multimedia and sensor networks fields are not suitable for multimedia communication in WMSNs, because they do not have enough consideration on the characteristics of multimedia streaming data and natural constraints of sensor networks at the same time. TPGF has been one of the recent developments that is geographic routing algorithm and takes care of multimedia communication.

Generally, multimedia transmission in WMSNs should consider the following three requirements:

• **Multipath transmission**: Packets of multimedia streaming data generally are large in size and the transmission requirements can be several times higher than the maximum transmission capacity (bandwidth) of sensor nodes. This requires that multipath transmission should be used to increase transmission performance in WMSNs[5]. Also multipath can be useful for fault tolerance, reliability, security, load balancing etc.

• **Hole-bypassing**: *Dynamic holes* may occur if several sensor nodes in a small area overload due to the multimedia transmission. Efficiently bypassing these *dynamic holes* is necessary for transmission in WSNs.

• **Lifetime of Network**: These networks should function for as long as possible. It may be inconvenient or impossible to recharge node batteries. Therefore, all aspects of the node, from the hardware to the protocols, must be designed to be extremely energy efficient.

• **Useful Paths**: Multimedia applications generally have a delay constraint, which requires that the multimedia streaming should always use paths that have end-to-end delay less than the delay constraint. Such paths can be called useful paths.

Multimedia transmission in WMSNs requires a new routing algorithm that can support all these four requirements at the same time. This paper proposes Application Aware Energy Efficient geographic Greedy Forwarding (AAEEGF), extension to Two-Phase geographic Greedy Forwarding (TPGF) routing algorithm for exploring one or multiple paths. The first phase of AAEEGF is responsible for exploring multiple node-disjoint paths. The second phase of AAEEGF is responsible for improving lifetime of paths explored.

Contributions in this paper are as following four aspects:

• **Key novelty**: To the best of our knowledge, AAEEGF is the first pure geographic greedy forwarding routing algorithm that focuses on supporting multimedia streaming in WMSNs, which supports the following features at the same time.

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• **Supporting multipath transmission**: AAEEGF can find multiple node-disjoint routing paths with path delay within time constraint of application.

• **Supporting hole-bypassing**: AAEEGF provides a better solution for hole-bypassing in both 2D and 3D sensor networks than other related research work.

• **Supporting optimized network lifetime transmission**: AAEEGF can find multiple paths with optimized network lifetime keeping delay constraint into consideration. Each path of multiple paths found, is checked for improving its lifetime.

In AAEEGF there is a trade-off between finding multiple node-disjoint paths and finding paths that have maximum lifetime, with priority being given to finding multiple node-disjoint paths. Thus, AAEEGF takes care of bandwidth and energy constraint at the same time keeping delay constraint of application into consideration.

II. NETWORK MODEL

In this paper, we consider a geographic wireless multimedia sensor network. The locations of sensor nodes and the base station are fixed and can be obtained by using GPS. Each sensor node has its transmission radius *TR* and *M*, 1-hop neighbor sensor nodes. Each sensor node is aware of its geographic location and its 1-hop neighbor nodes' geographic locations. We assume that only source nodes know the location of the base station and other sensor nodes can only know the location of base station by receiving the packet from source nodes. This assumption is the same with that used in [6]-[9]. Different applications have different time constraints within which data should be delivered from sender to the receiver. Time constraint of application A is denoted by T_a. The first sub-problem of this paper is to find *N* number of node-disjoint routing paths, $P = \{p_1, . . . , p_n\}$ with least number of nodes such that end-to-end transmission delay d_i of path p_i satisfies time constraint T_a of application. Here all N number of paths should be useful for the application. No paths explored should have end-to-end delay greater than time constraint.

The second sub-problem is to maximize lifetime of the N paths found by using pool of available nodes keeping end-to-end delay within time constraint. The number of node disjoint paths remains same where as lifetime of paths should be increased wherever possible. The problem can be stated as finding maximum number of node-disjoint routing paths from source node in network layer with improved lifetime of paths. All paths explored should be useful i.e. path delay should be within time constraint.

III. AAEEGF ALGORITHM

Motivated by the two sub-problems AAEEGF consists of two phases: *Application aware geographic forwarding* and *lifetime improvement within time constraint.*

Definition 1 : A *node-disjoint* routing path is defined as a routing path that consists of a set of sensor nodes excluding the source node and the base station. None of these sensor nodes can be reused for forming another routing path. In AAEEGF, all the found routing paths are *node-disjoint* routing paths.

Definition 2 : An *useful path* is defined as a routing path that has end-to-end delay within time constraint of the application.

In AAEEGF, all the found paths are useful paths. This feature of exploring useful paths and not the paths that have end-to-end delay greater than time constraint should be used because of two reasons. The first reason is nodes that would have been blocked or made unavailable due to its inclusion in useless paths, would now be available for constructing other useful paths. This would increase number of useful paths explored. The second reason being that, the responsibility of transport layer to select useful paths out of all paths found in network layer, is reduced. This would save energy at each node, which would have been spent in implementing all the protocol layers of the model. AAEEGF routing algorithm is trade-off between finding maximum node-disjoint paths and finding paths with maximum lifetime.

A. Application aware Geographic forwarding

The first phase addresses the first sub-problem: exploring maximum number of useful node-disjoint routing paths while bypassing holes in WMSNs. Finding multiple node-disjoint paths have multiple benefits when multimedia data is considered in WSNs. All routing paths that are explored should be useful, and no node should be blocked in construction of paths whose end-to-end delay does not satisfy time constraint of application. This phase is similar to TPGF but here paths are found in accordance to delay constraint from application. Selection of nodes for path construction is dependent on the time constraint and is thus adaptive to application in use. In contrast, TPGF always finds same set of paths irrespective of application in demand. Being application aware, time constraint information is passed from application layer to network layer. All possible node-disjoint routing paths within time constraint are then explored. Nodes are involved in useful path construction. TPGF constructs both, useful as well as useless paths. Nodes get blocked in construction of useless paths in TPGF, decreasing the count of available nodes that can be considered for useful path construction. So, less number of useful paths may be constructed in TPGF than AAEEGF.

To accomplish this objective, the algorithm works in two sub phases- *Finding node-disjoint paths* and *optimization of paths*.

1) *Finding node-disjoint paths :* In this sub phase, node-disjoint path is explored based on availability of nodes and time constraint of application. Finding disjoint paths consists of two methods- Greedy forwarding to useful node and backtracks and mark free. The principle for Greedy forwarding to useful nodes in this paper is: a forwarding node always chooses the next hop node that is closest to the base station among all its neighbor nodes and next hop can be farther to base station than itself and moving to the node keeps path's delay till that neighbor node within delay constraint of application.

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The greedy forwarding principle is different from greedy forwarding principle in TPGF. In TPGF next hop is selected, marked and used even if nodes in a path may not form useful path. Paths found are not application specific, so nodes forming paths with end to end delay greater than delay constraint cannot be used for finding some other useful paths. But in AAEEGF, paths are application specific, so selection of next hop is based on application delay constraint. Nodes are marked and used only if they are part of useful paths. Since AAEEGF is extension to TPGF, AAEEGF is also free from Local Minimum Problem, which exists in some greedy forwarding algorithm. For any sensor node, during the exploration of a routing path, if it has no next-hop node that is available or moving to which doesn't satisfy delay constraint for transmission, except its previous-hop node, this node is defined as a free node for construction of other useful paths and blocked for the same path construction. To handle this situation we propose the backtrack and mark free approach: When a sensor node finds that it has no next node to move or moving to neighbor node violates delay constraint , it will step back to its previous-hop node and mark itself as free node, making itself available for other useful path construction. The previous node now tries to find another available neighbor node as next hop node. If next node is still not available for useful path construction then we further backtrack until we either get a next node for useful path construction or cannot find a useful path from source node to the based node. If no useful paths can be found from source node, searching for paths stops and list of paths obtained so far is the result of phase -1, finding multiple disjoint paths.

2) *Path Optimization :* This sub- phase is responsible for solving the second sub-problem: optimizing the found routing paths with the least number of nodes. The *path optimization* includes one method: *label based optimization.* For any given routing path in a WMSN, if two or more than two sensor nodes in the path are neighbor nodes of another sensor node in the path, we consider that there is a path circle inside the routing path. A routing path found by *geographic forwarding* phase in AAEEGF can have *path circles*, which actually can be eliminated for reducing the number of nodes in the routing path. It is clear that the routing paths found by AAEEGF can be optimized to have the least number of routing nodes by eliminating all *path circles* . To eliminate the *path circles* in the routing path, we use same principle as in TPGF, *label based optimization*, which needs to add an additional function in the *geographic forwarding* phase. Whenever a source node starts to explore a new routing path, each chosen node is assigned a label that includes a path number and a digressive node number. Whenever a routing path reaches the base station, an acknowledgement is requested to send back to the source node. During the reverse travelling in the found routing path, the *label based optimization* is performed to eliminate the *path circles*. The principle of the *label based optimization* is: Any node in a path only relays the acknowledgement to its one-hop neighbor node that has the same path number and the largest node number. A release command is sent to all other nodes in the path that are not used for transmission. These released nodes can be reused for exploring other additional paths. This sub-phase is same as used in TPGF and may reduce number of hops in a path.

B. *Lifetime Improvement within time constraint*

Definition 3 : A *culprit node* in a path is the node which expends energy at highest rate and path's lifetime depends upon its lifetime because culprit node would be the first node in the path to become dead after draining all its energy. The aim of this phase is to improve lifetime of multiple paths found during phase-1. Phase-1 results in exploring maximum number of disjoint paths from source node. This set of paths is then fed as input to phase-2 where intermediate nodes are added from pool of available nodes. Adding nodes is in accordance with the delay constraint of application. In a way, path delay is normalized to delay constraint.

Adding of intermediate nodes to set of paths is based on priority of paths. This priority is based on lifetime of paths. Assuming all sensor nodes are initialized to equal energy, sensor node expends energy proportionate to distance between sender and receiver. We assume a simple model for the radio hardware energy dissipation where the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics, as shown in Fig. 1.

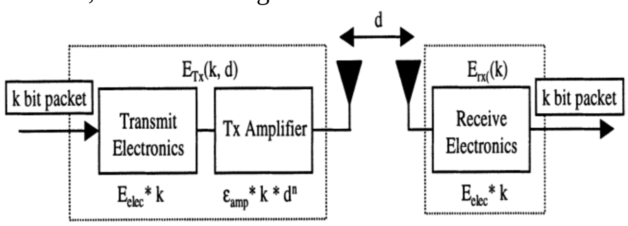

Fig.1 Radio Hardware energy dissipation model

Both the free space (d^2 power loss) and the multipath fading (d^4 power loss) channel models are used, depending on the distance between the transmitter and receiver. Power control can be used to invert this loss by appropriately setting the power amplifier. If the distance is less than a threshold d_0, the free space (f_s) model is used; otherwise, the multipath model is used. A sender node with greater sender and receiver distance expends more transmission energy than one with less distance between them. Assuming computational power consumed by each sensor node to be constant, node's energy depends on transmission power of the nodes. Paths lifetime solely depends on the lifetime of the culprit node. Since culprit node is sure to drain all energy first, we try to burden off the culprit node by introducing new sensor nodes in between, so that maximum transmission distance is decreased for any node in the path. Now some other node with less distance to transmit becomes the *culprit node.* Lifetime of the path increases as rate of draining energy decreases for the culprit node.

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In AAEEGF, paths are sorted based on priority i.e. path with higher maximum inter-node distance has the highest priority. It means that such paths are in greater need for lifetime improvement than a path with less maximum inter-node distance. Once paths are sorted, the path with highest priority is selected. The available neighbors of culprit node of selected path are then sorted based on its distance from mid-position of culprit node and present next node in the path. Let C_{mid} be coordinate of mid position of culprit and next node, C_{cul} be coordinate of culprit node and $C_{nexthop}$ be coordinate of next hop node, $C_{neighbor}$ be coordinate of available neighbor of the culprit node and D be the distance of C_{mid} from $C_{neighbor}$. Sorting of neighbor nodes is done based on this distance D. This sorting is done so that nodes lying mid way between culprit and next node gets higher priority. This ensures selection of intermediate nodes that reduces transmission distance effectively. Each node is then checked for inclusion in the path after culprit node. If the distance D_{cul} between neighbor and culprit and distance D_{nhop} between neighbor and next node are both less than the D_{max} (distance between culprit and next hop node) then neighbor is selected as intermediate path. Before inserting the intermediate node it is also checked whether the extra delay introduced in the end to end path keeps total delay less than delay constraint of application or not.

Condition checked will be:

(Present path delay + Extra delay by introducing new node) ≤ Delay Constraint of Application and

$D_{cul} < D_{max}$ and $D_{nhop} < D_{max}$.

If any neighbor of culprit satisfies the condition, it is included between culprit and next hop neighbor. If no neighbor satisfies the condition then it means that path's lifetime cannot be improved from current pool of available sensor nodes as paths are constrained to be disjoint. In such cases, next path in the sorted list is considered and same process is repeated for this path. If no path in the list can be improved then algorithm terminates. If a path's lifetime is improved by introducing intermediate node then culprit node for that path is recalculated to get new culprit node. Whole list of paths are again sorted based on maximum distance between any two consecutive nodes in the path. After the list is sorted same process of improving lifetime is repeated. But it is taken care that paths whose lifetime could not be improved in previous processes do not participate in the process of improving lifetime again.

C. Simultaneous Multipath Transmission

AAEEGF finds maximum number of disjoint paths with improved lifetime, simultaneously with the guarantee that paths are node-disjoint and within delay constraint of application. List of energy efficient paths are displayed. List of paths obtained are trade-off between finding maximum lifetime paths and maximum number of parallel disjoint paths. Here priority is given to find the maximum number of parallel disjoint paths and then algorithm is applied to improve lifetime of those paths. This entire path finding process takes delay constraint into account and makes sure no path's end-to-end delay is greater than delay constraint of application in context.

D. *Comparision with the TPGF*

AAEEGF is extension of TPGF algorithm. Unlike TPGF, no nodes are blocked in exploring paths that has end-to-end delay greater than time constraint. Thus more available nodes may be present in AAEEGF than in TPGF for exploring more number of node-disjoint paths. AAEEGF also maximizes lifetime of paths but in TPGF no care is taken to improve paths lifetime. All resulting paths of AAEEGF are useful paths unlike TPGF. In TPGF, number of disjoint paths is found statically irrespective of application in context whereas in AAEEGF, number of disjoint paths is found dynamically based on application delay in consideration. In TPGF, paths are found merely on the basis of distance of neighboring nodes (next nodes in consideration) from the sink node. The node which is nearest to the sink node is picked if a path can be formed using that node irrespective of the end to end delay of the path but in AAEEGF, paths are found keeping delay constraint in mind. In AAEEGF we select nodes that lead to useful paths and neglect those that may lead to useless path (not satisfying delay constraint). Thus, these nodes may be utilized in some other paths construction. In TPGF, all disjoint path calculation takes place at network layer and then this information is passed to the transport layer for path selection based on delay constraint of application. But in AAEEGF there is cross layer concept employed where Application layer information (delay constraint) which is application dependent is passed directly to the network layer. Based on this information best paths are chosen (paths that satisfy the time constraint and can be used). These paths are then normalized within delay constraint to improve paths lifetime.

IV. SIMULATION AND EVALUATION

In this simulation, we consider a WMSN for different applications with different time constraints. Path whose end-to-end delay is greater than time constraint of the application cannot be used for data transmission and hence termed useless. The end-to-end transmission delay in WMSNs is actually determined by the number of hops. Thus, to find out the path with end-to-end delay within time constraint of application is to find paths with hop number not exceeding upper bound on number of hops as: $D_{e2e} = H \times D_{hop}$, where H is the number of hops and D_{hop} is the average delay of each hop. The parameters used in our simulation are shown in TABLE-I. Time constraint of application has been varied to compare number of disjoint paths available for data transmission within time constraint in various cases. It would also clearly distinguish the performance of both the algorithms in adapting to the application in use. Fig. 2 shows the sensor network deployed for simulation.

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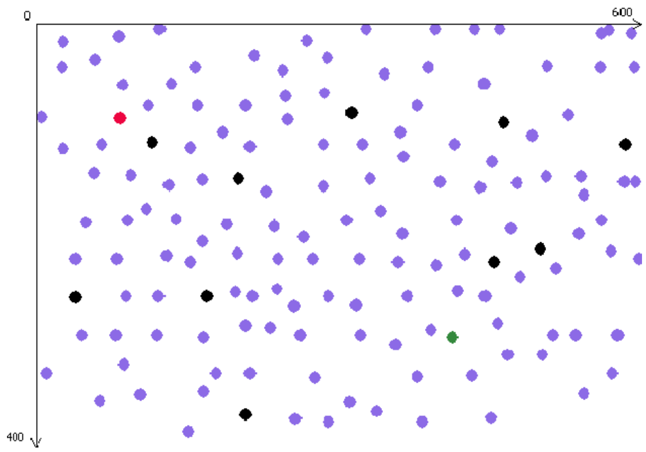

Fig.2 Showing sensor network deployed for simulation

Table 1 Parameter Table

Simulation parameters	Parameter Value
Network size	600m * 400m
Number of base station	1
Number of sensor nodes	150
Number of source nodes	1
Sensor node transmission radius	60m
Delay of each hop D_{hop}	20ms
Application time constraint	140ms to 240ms

To demonstrate and evaluate AAEEGF, we use a new open source WMSN simulator called NetTopo [10]. For simulation purpose we have deployed a network of 150 sensor nodes and one source node and one sink node. Application time constraint is varied from 140 ms to 240 ms. For 140 ms as time constraint, both the algorithms fail to explore single path within time constraint. The Fig. 3 shows the path obtained by AAEFGF in contrast to no useful paths obtained by TPGF within 160 ms.

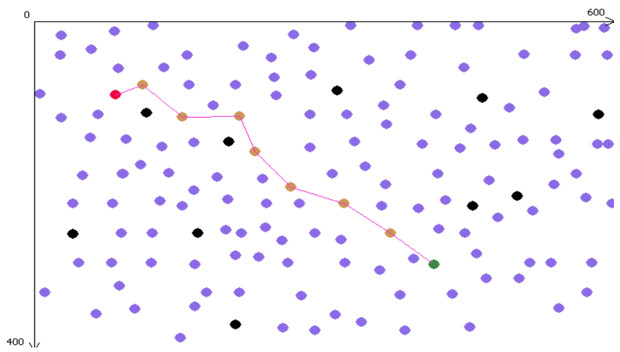

Fig. 3 Shows one path explored using AAEEGF when time constraint is 160 ms. No path is explored using TPGF for this application.

Varying time constraint further, we get either same or more count of paths using AAEEGF than TPGF. The simulation result of number of useful paths obtained from both the algorithm has been shown in the TABLE-II. For 180ms we get same path from both the algorithm. This path is different from one obtained from AAEEGF for time constraint 160ms. Simulation result for time constraint 200 ms shows three paths obtained from AAEEGF while only one useful path could be explored using TPGF.

Table 2 Time constraint comparision

Time constraint(ms)	TPGF	AAEEG F
140	0	0
160	0	1
180	1	1
200	1	3
220	3	3
240	4	4

In this paper we have shown simulation result of one of the test scenarios. Various other scenarios were also implemented to test the effectiveness of AAEEGF over TPGF. In almost all cases, AAEEGF either explores same or more number of node-disjoint paths within time constraint. From the above test scenario we can conclude that AAEEGF adapts to the application. For 160ms and 180ms, AAEEGF produces one path, but both paths are different. TPGF always produces same set of paths irrespective of application. In TPGF nodes get blocked in construction of paths that may be useless but AAEEGF adapts to the application need and has equal or more number of available nodes for useful path construction. We can now conclude that AAEEGF produces better number of node-disjoint useful paths than TPGF.

The paths explored by TPGF and first phase of AAEEGF can be further improved in terms of network lifetime. These paths were explored with the aim to have shortest and optimized paths. More number of hops can be added to these paths if they tend to increase paths lifetime and still can be useful in terms of time constraint. In the second phase of simulation, we show results after applying lifetime improvement algorithm to the output of first phase. The path's lifetime depends on node that expends energy at the highest rate(culprit node). Here intermediate nodes are introduced in the path to share the burden of culprit node by reducing the transmission distance. This phase totally depends on the availability of sensor nodes in the vicinity of culprit node and time constraint. All manipulations in the paths are done within time constraint. Simulation results have been shown in the TABLE-III. Number of total paths, number of paths with improved lifetime and reduction in transmission distance for most affected path has been shown for various time delays.

Table 3 Path liftime improvement

Time constraint (ms)	Total paths	Improve d paths	Reduction in Max Transmission Distance of most affected path
140	0	0	0
160	1	0	0
180	1	0	0
200	3	1	60 - 58.89821
220	3	0	0
240	4	1	59.9082 - 56.7274

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260	4	2	59.9082 - 56.7274

The gain in energy is proportional to difference in square of the transmission distance or difference in quadruple of transmission distance of culprit node. The number of improved paths depends on availability of nodes in vicinity of culprit node and time constraint of application. From the above simulation, it can be seen that paths lifetime have been improved within time constraint wherever possible. All the paths that have been explored with improved lifetime are within time constraint and are all useful. But, TPGF being application independent explores paths that may be useless for the application.

V. CONCLUSION

In this work we presented application time constraint aware routing algorithm that adapts its path according to the time constraint and has better lifetime within time constraint. The number of paths and nodes forming the paths depends on the time constraint of the application. Nodes inclusion in path construction is adaptive. We believe that our research can make a significant impact on both mobile multimedia and WMSN research communities.

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