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TDMA Scheduling with Leach protocol

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ABSTRACT: In this paper, we propose a solution to the scheduling problem in clustered wireless sensor networks (WSNs). The objective is to provide network-wide optimized time division multiple access (TDMA) schedules that can achieve high power efficiency, zero conflict, and reduced end-to-end delay. To achieve this objective, we first build a nonlinear cross-layer optimization model involving the network, medium access control (MAC), and physical layers, which aims at reducing the overall energy consumption. We solve this problem by transforming the model into two simpler sub problems. Based on the network-wide flow distribution calculated from the optimization model and transmission power on every link, we then propose an algorithm for deriving the TDMA schedules, utilizing the slot reuse concept to achieve minimum TDMA frame length. Numerical results reveal that our proposed solution reduces the energy consumption and delay significantly, while simultaneously satisfying a specified reliability objective.In wireless sensor networks (WSNs), due to the limitation of nodesenergy, energy efficiency is an important factor should beconsidered when the protocols are designing. As a typical representative of hierarchical routing protocols, LEACH Protocol plays an important role. In response to the uneven energy distribution that is caused by the randomness of cluster heads forming , this paper proposes a new improved algorithm ofLEACH protocol (LEACH-TLCH) which is intended to balance the energy consumption of the entire network and extend the life of the network . The new algorithm simulation results indicate that both energy efficiency and the lifetime of the network are better than that of LEACH Protocol.

KEYWORDS: LEACH Protocol; Energy consumption; Network lifetime

I. INTRODUCTION

SCHEDULING of medium access plays an important role in the performance of wireless sensor networks (WSNs). In the literature, time division multiple access (TDMA) and carrier sensing multiple access (CSMA) are two major medium access approaches in WSNs. This work will only focus on the TDMA approach because the scenario specification of our research is a static network in which TDMA is said to be more effective than CSMA, especially under medium to high traffic load. In this paper, we aim at deriving TDMA schedules with optimized power consumption and minimum latency in clustered WSNs. Energy efficiency is a major concern in WSNs, since the batteries are often impossible to be replaced or recharged in many cases in TDMA.

LEACH Protocol is the first protocol of hierarchical routings which proposed data fusion, it is of milestone significance in clustering routing protocols. Many hierarchical routing protocols are improved ones based on LEACH protocol. So, when wireless sensor networks gradually go into our lives, it is of great significance to research on LEACH protocol.

II.LEACH PROTOCOL

LEACH Protocol is a typical representative of hierarchical routing protocols. It is self-adaptive and self-organized. LEACH protocol uses round as unit, each round is made up of cluster set-up stage and steady-state stage, for the purpose of reducing unnecessary energy costs, the steady-state stage must be much longer than the set-up stage. The process of it is shown in Figure.

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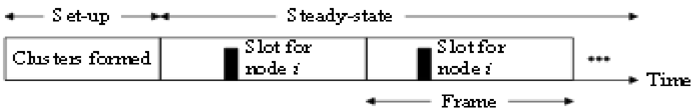

Fig.1 LEACH Protocol process.

At the stage of cluster forming, a node randomly picks anumber between 0 to 1, compared this number to thethreshold values $t(n)$, if the number is less than $t(n)$, thenit became cluster head in this round, else it becomecommon node. Threshold $t(n)$ is determined by thefollowing:

$$t(n) = \begin{cases} \dfrac{p}{1 - p * (r \bmod \frac{1}{p})} & if\ n \in G \\ 0 & if\ n \notin G \end{cases}$$

III. RELATED WORK

Earlier works on TDMA scheduling for WSNs mainly focus on obtaining the shortest schedules , or distributed implementation In non-conflicted schedules are obtained first, and a following algorithm then goes through all nodes and slots, in turn, to produce maximal broadcasting sets, thus reducing the schedule length. The authors of further take into account the number of packets being sent at every node, and provide the shortest schedules by eliminating the nodes without packets to send at each loop of the proposed algorithm. Compared to the approaches demanding global topology information, distributed scheduling is more flexible, but at a cost of increased schedule length.

In LEACH protocol, due to the randomness of clustersforming, the energy of cluster head is very different, so do the distances between cluster heads and base station.Cluster heads are responsible not only for sending data tothe base station but also for collecting and fusing the datafrom common nodes in their own clusters. In the process ofdata collection and transmission, the energy consumed bydata transmission is greater than that of data fusion . Ifthe current energy of a cluster head is less or the distanceto base station is much far, then the cluster head will bedied quickly because of a heavy energy burden. To addressthese issues, this article proposes a new improvedalgorithm on how to balance the energy loads of thesecluster heads.

IV.SYSTEM MODEL

i) NETWORK ARCHITECTURE

The nodes in the network are divided into multiple clusters, each comprising a CH and cluster members thatcommunicate via one hop to the CH.A graph G = (V, L) is used to denote the backbone. Where V is the set of nodes and L the set of links.Henceforth, in this paper, the term network refers to thebackbone network with node set of V and link set of L. Thetotal number of nodes in the network isN = |V| , in which thesink is taken as node #1, without loss of generality. If amaximum transmission power is specified, we use G = (V, L’), instead of G = (V, L), where L’, a subset of L, is the setof links that can be formed according to the specifiedmaximum transmission power Ptx,max. A link (i, j) is validonly if (i, j) € L’ The links are unidirectional so that link (i , j) and link (j , i) are two different links. We assume that thesensor nodes in the network are stationary, for simplicity.

ii) PHYSICAL LAYER

A realisticphysical layer model considers the propagation model, modulation, encoding, demodulation, and decoding techniques,thus linking major parameters such as power, signal to noise ratio (SNR), and bit error rate together. Examples of such a physical layer model can be found.

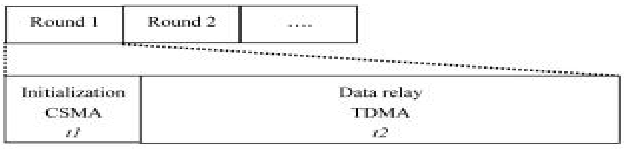

Fig. 2. Operation rounds.

In this paper, we use the following path loss model [19]:

$$Pl(d) = Pl(d_0) + 10\gamma \log 10(d/d_0), \qquad (1)$$

iii)MAC LAYER

As stated in Section 1, the TDMA scheme is the MAC layer protocol employed during the data relay phase. A TDMAframe consists of a number of slots, each with fixed length ΔtWe assume that NACKs and retransmissions are used at theMAC layer. However, to simplify the analysis and the scheduling algorithm, we neglect the cost of NACKs by assuming that a NACK is only generated once in each fixed feedback period to inform the source nodes of packets not correctly received in the last period. Given the packet loss rate p, the per-hop average number of total transmissions for a packet to be successfully received is 1= (1 – p).

V. CROSS-LAYER OPTIMIZATION MODEL

Across layeroptimization model is formulated as follows:

$$\begin{aligned} & \textit{minimize} \\ & \left(\sum_{i=2}^{N}\sum_{j=1}^{N} E(P_{tx,ij}) \frac{1}{1-p_{ij}} f_{ij} + \sum_{i=2}^{N}\sum_{j=2}^{N} E(P_{rx}) \frac{1}{1-p_{ij}} f_{ij} \right. \\ & \left. + \sum_{i=2}^{N} \lambda_i E(P_{rx}) + \sum_{i=2}^{N}\sum_{k=1}^{N_{SN,i}} [E_{sens,k} + E(P_{tx,ki})(\lambda_i / N_{SN,i})] \right), \\ & (i,j) \in L', i \neq j \end{aligned} \qquad (6a)$$

$$\text{s.t.} \quad f_{ij} \geq 0, \; i \in [2, N], j \in [1, N], i \neq j, \qquad (6b)$$

$$f_{ij} = 0 \quad iff \; (i,j) \notin L' or \; i = j, \qquad (6c)$$

$$\sum_{j=1, j\neq i}^{N} (f_{ij} - f_{ji}) = \lambda_i / C_i, \quad i \in [2, N], \qquad (6d)$$

$$\sum_{i=2}^{N}\sum_{j=1}^{N} \frac{1}{1-p_{ij}} f_{ij} \leq R, \quad i \neq j, \qquad (6e)$$

$$\begin{aligned} & \sum_{j=1, j\neq i}^{N} \left(E(P_{tx,ij}) f_{ij} \frac{1}{1-p_{ij}} + E(P_{rx}) f_{ji} \frac{1}{1-p_{ji}} \right) \\ & + \lambda_i E(P_{rx}) \leq e_i \quad i \in [2, N], \end{aligned} \qquad (6f)$$

where E(Ptx,ij) is the per bit average transmission energyconsumed at node i when transmitting to node j usingtransmission power Ptx,ij, pij is the packet loss rate onlink (i,j), fij is the data flow rate (in bits per second) fromnode i to j without accounting for the retransmissions, λ_i isthe new generated traffic (in bits per second), Ci is the trafficaggregation factor at node i if node i is a source CH, at node i (e.g.,$e_{i,}e_{i,}$avail/T, where$e_{i,}$availis the initial available energy inmill joule (mJ) at node i and T is a fixed lifetime in seconds).The objective function in (6a) gives the total consumedenergy of the whole network per unit time (i.e.,mJ/sec = mW), which is composed of transmission andreceiving mode energy consumption at all backbone nodesexcluding the sink (the energy consumed at the sink isneglected because its power source is replaceable), and theenergy consumed by each active sensor node (clustermember) in sensing and transmitting the data to its CH.

$$\left(\sum_{i=2}^{N} \sum_{j=1}^{N} E(P_{tx,ij}) \frac{1}{1-p_{ij}} f_{ij} + \sum_{i=2}^{N} \sum_{j=2}^{N} E(P_{rx}) \frac{1}{1-p_{ij}} f_{ij} + \sum_{i=2}^{N} \lambda_i E(P_{rx}) \right), \quad (i,j) \in L', i \neq j. \tag{6a'}$$

The first two constraints (6b) and (6c) state that the flowrate should be nonnegative and flows can only exist on valid links. The third constraint (6d) indicates that theoutput data rate at each node should be the sum of inputdata rate and data generation rate at that node (the data aregenerated by cluster member nodes, aggregated at thecorresponding CH, and then, relayed to the sink). Thefourth constraint (6e) is the data rate or bandwidth limit ofthe network, showing that the summed data rate withretransmissions at all links should not be greater than themaximal allowed data rate. This is a conservative constraint,since slots can be reused in our model. The fifthconstraint (6f) is the per unit time energy consumptionconstraint at every node.The optimization model depicted by (6) is cross-layer based because it jointly combines network layer traffic loads,MAC layer retransmission scheme, and physical layer
modulation scheme and bit error rate together, in order toderive appropriate transmission power Ptx,ij and flow rate fijat every link (i, j),(i, j) belongs toL'; i≠ j, to achieve network-wideoptimal power efficiency. Applying (2)-(5), this model isobviously nonlinear due to the terms $E(P_{tx,ij})$(1/1-pij)and$E(P_{rx})$(1 /1-pij)belongs toL'; i≠ j, which are, respectively, thetransmit and receive energy consumed in relaying a bit fromnode i to j. Solving this nonlinear optimization problemdirectly is a nontrivial task, so we transform the problem intotwo simpler subproblems. We, therefore, propose to solvethe following subproblem #1 first.
Sub_Problem #1:

$$\begin{aligned} \text{min.} \quad & (E(P_{tx,ij}) + E(P_{rx})) \frac{1}{1-p_{ij}} (i,j) \in L' \\ \text{s.t.} \quad & lb < P_{tx,ij} < ub \quad i \in [2,N], j \in [1,N], i \neq j, \end{aligned} \tag{7}$$

where lb and ub are the lower and upper bounds of thetransmission power, respectively. The purpose of subproblem#1 is to find the optimal transmission power onLink (i, j)$P_{opt,tx.ij}$ in order to consume the least energy
$E_{opt,I,j,txrx}$for transmitting a bit from node i to j. Subproblem#1 is actually a simple problem of deriving theminimum value of a function. Numerical methods such asgolden section search [23] can be adopted to solve thisproblem. The solution to (7) then serves as input to (6).However, before being able to use the results of (7) asinput to (6), we need to prove that the optimal transmissionpower on each link obtained from solving (6) is equivalentto that obtained from solving (7).

VI. IMPLEMENTATION

Solving the optimization model in (6) gives the flowdistribution and transmission power on every link, whichachieves the energy-efficient data relay. We can, of course,calculate the TDMA slots assigned to every link accordinglywithout slot reuse. However, this results in very longTDMA frame length, and thus, unacceptable delay in largesizeWSNs. Our goal then is to derive a relationshipbetween the delay incurred by a data packet at eachbackbone network node (along its path to the sink) and theTDMA frame length M so that, by reducing the framelength through slot reuse, the delay is minimized. For thisanalysis, we determine the node delay from the instant thefirst bit arrives at the node until the time the last bit exits thenode. With the TDMA MAC adopted, the nodal delay canbe approximated by the time interval

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between the inputtime slot where the data are read and the output time slotfrom which the data are read out. Suppose the data packetis received at a node in slot m1, m1 belongs to [1,M], and relayed outin slot m2, m2 2 [1,M] the delay experienced by the relayeddata packet at this node is

$$D(m1, m2) = \begin{cases} m2 - m1, m2 > m1, \\ M - m1 + m2, m2 < m1, \end{cases} m1, m2 \in [1, M]. \tag{9}$$

Assuming that m1 and m2 are independent of each other,the average delay experienced by the data packet at thisnode is then

$$\frac{\sum_{m2=1, m2 \neq m1}^{M} D(m1, m2)}{M-1} = \frac{M}{2}, m1 \in [1, M], \tag{10}$$

from which we conclude that reducing the TDMA framelength translates to a reduction in nodal delay. The end-toenddelay is the sum of the nodal delays along a path to thesink, plus the associated propagation delays which arenegligible due to short distances between the backbonenodes. Hence, minimizing the TDMA frame length alsominimizes the end-to-end delay. Next,weapply the slot reuseconcept to achieve a reduction inTDMAframe length. That is,a slot already assigned to a link can be reused at another linkprovided that the interference between the two links is belowa specified threshold. In the following, a scheduling schemethat implements the slot reuse concept is presented.The first step is to determine the number of slotsrequired by each link in the backbone network and thevirtual link in each cluster. For a backbone link i,j withflow f_{ij}, maximum data rate R (both in bits per second), andper-hop packet loss rate p_{ij}, the slots needed (each oflength Δt) per second are:

$$M_{ij} = \left\lceil \frac{f_{ij}}{R \Delta t (1 - p_{ij})} \right\rceil, \quad i \in [2, N], j \in [1, N], \tag{11}$$

where [x] is the smallest integer greater than or equal to x. Note that the slot length Δt should be selected as small aspossible to reduce the error introduced by the ceilingfunction in (11). Also, note that the flow distribution f_{ij}derived from the optimization model in (6) need not beuniform for all the links; hence, the M_{ij} can be different fordifferent links. Let $M_{v,i}$ denote the number of slots requiredby the virtual link directed to CH i, which is determined byCH i according to the aggregate intracluster traffic, andthen, sent to the sink. The sink uses the virtual link slotrequirements, along with the corresponding requirementsfor the backbone links to determine the slots needed persecond at each node i (CH or gateway):

$$M_i = \begin{cases} M_{v,i} + \sum_{j=1}^{N} M_{ij}, \ i \in CHs, \\ \sum_{j=1}^{N} M_{ij}, i \in Gateways, \end{cases} i \in [2, N], i \neq j. \tag{12}$$

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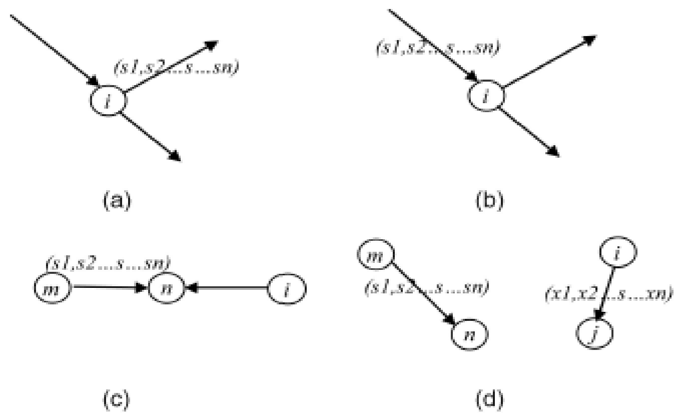

Without slot reuse, the TDMA frame length is, $\sum_{i=2}^{N} M_i$, which can become too long (i.e., too long delay) for a largesizebackbone network.

Criterion 1. Node i is not the sender or receiver of a previouslyscheduled link using slot s, and the link of node i to bescheduled with slot s does not have the same receiver as that ofa previously scheduled link currently assigned slot s.
Criterion 2. Scheduling s as a slot used by one of node i's linkscauses negligible interference to the receiver of a previouslyscheduled link also using slot s.
Criterion 3. The sender of a scheduled link using slot s causesnegligible interference to the current receiver if it is usingslot s on one of node i's links.

Algorithm 1. Incremental heuristic for conflict free TDMA frame slot assignment (implemented at the sink)
Input: *backbone network graph* $G = (V, L)$, M_i, d_{ij} & $P_{ix,ij}$
Output: *Conflict-free schedule with frame length* M

```
for each node i(i ≠ sink) of V do
    for each required slot m in M_i do
        Try assigning slot s = 1;
        while any of the 3 interference criteria is not
        satisfied do
            Try assigning the next slot s = s + 1;
        end while
        Assign slot s to required slot m of node i;
    end for
    Store the Id of the last slot s assigned to node i, Γ_i = s;
end for
Calculate the frame length M = max{Γ_i}, ∀i ∈ {2, N}
```

After deriving M, which is the maximum slot ID beingassigned in Algorithm 1, one must verify that $M\Delta t \leq 1$.This means that the frame duration should be less than1 second in accordance with the definition ofM_i. Otherwise,smaller values of Δt are needed to regenerate M until$M\Delta t \leq 1$. In this algorithm, and also in the optimizationmodel described in Section 4, we assume that the distancebetween every two nodes is known, and the sink can obtainthe distance information during the deployment phase of aWSN, or by GPS devices.

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VII. SYSTEM USABILITY AND PERFORMANCE EVALUATION

Simulation scenarios:

1. Sensor nodes are randomly distributed in a squareregion;
2. Sensor nodes are homogeneous and have a unique IDnumber throughout the network, nodes energy is limited. The node's location is fixed after deployed;
3. The base station is in the centre of region with fixedlocation;
4. Nodes communicate with base station via single-hop ormulti-hop;
5. The wireless transmitter power is adjustable.

The network lifetime:

In WSN, the network life is divided intostable and unstable period [6]. Stable period usually meansthe time from the beginning of the simulation to the timewhen the first node dies, the unstable period refers to thetime from the death of first node to the end of simulation.If it happened that some nodes begin to die, the networkoperation may become unstable and unreliable datatransferring will occur. Therefore, the longer the stableperiod is, the better the performance of the network. InLEACH Protocol, cluster heads are responsible not onlyfor communicating with the base station, but for the datafusing. Randomly distributing the nodes and randomlyselecting the cluster heads causes some cluster heads dieearlier because of the low energy or the long distance tobase station. Secondary cluster heads are set for theseclusters to be responsible for the communication withcommon nodes and data fusing; this balances the energyload of cluster heads and avoids premature death of thesecluster heads, so the stable period of network lifetime willbe prolonged.

The total energy consumption:

Improved algorithm reduced the energy consumption of few cluster heads which has low energy or is far away to base station by setting secondary cluster heads reasonably. This balanced the energy consumption of the whole networks extended the lifetime of cluster heads which may dieearlier and optimized the performance of the networkthereby reduced the total energy consumption of theeffective lifecycle.We know that in the wholerunning of the network, the energy consumption ofimproved algorithm is much lower than that of LEACHProtocol at the same round of simulation. These results areconsistent with the design purposes of improved algorithm.

VII. CONCLUSION

Realizing the relationship between the transmission powerand retransmissions on a link determining the optimaltransmission power, we build a cross-layer design-basednonlinear optimization model which aims at minimizingthe network-wide energy consumption. We solve thisproblem by transforming it into two subproblems with lesscomplexity. Based on the results obtained from the model,we further propose an algorithm that provides a conflictfreeschedule utilizing the slot reuse concept. The schedulingalgorithm can be applied to WSNs with non-uniformlydistributed traffic and different link transmission power.Electing cluster head randomly causesthat the current energy of some cluster heads are less ortheir distances to base station are far, because of the heavyenergy burden, these cluster heads will soon die. For thisissue, this article proposed a new improved algorithm with LEACH protocol which is aim at balancing energyconsumption of the whole network and extending thenetwork lifetime by balancing the energy consumption ofthese cluster heads. the simulation resultsindicate that the energy efficiency and the lifetime ofnetwork are both better with LEACH Protocol.

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