CHAPTER 4

EXTENDING LIFETIME USING ENERGY EFFICIENT CLUSTER TREE BASED DATA GATHERING ALGORITHM IN WSN

4.1 OVERVIEW

Wireless Sensor Network (WSN) has become imperative in today’s real world applications, since the gathered information by the sensors is essential for Industrial Application. Moreover the WSN has acquired two unique characteristics when compared to other commercial wireless communication systems: (i) the sensors have been equipped with a limited energy resource and (ii) the information collected by the nodes is redundant. These characteristics cause high energy consumption and heavy data traffic over the network. The efficiency of WSNs simply relies on the data gathering scheme. Different data gathering scheme has been available like multipath routing, clustering, tree and cluster tree for gathering useful information in WSNs. The existing data collection schemes have not been up to snuff to ensure an assured reliable network in terms of traffic and end to end connection. So this chapter presents an Energy Efficient Link aware Cluster Tree based algorithm for finding optimal path in order to gather the data in an efficient way.

4.2 INTRODUCTION

WSNs contain huge number of sensor nodes which are responsible for sensing the reliable data from the environment and collaboratively work
together and route the reliable information to the sink node. They possess a huge application value in the areas like battlefield, medical care, habitat monitoring and so on. In general, the tiny sensors are equipped with limited battery resources and communication abilities; hence it increases the challenge in reducing the energy consumption so as to improve the network lifetime. Data gathering has been identified as one of the essential distributed procedures for data processing in WSN for effective energy utilization and reducing the MAC layer contention. Data gathering schemes work on data aggregation which is essential for information flow in an energy efficient way. In addition, the data gathering mechanism can minimize the communication cost and hence the lifetime of sensor networks can be improved. Therefore the concern of data gathering in an energy efficient way has been investigated extensively in the area and categorized into the chain based algorithm, cluster based algorithm, tree based algorithm and cluster tree based algorithm.

**Chain Based Algorithm:** The sensors have been grouped and deployed like a chain structure, the efficient sensor node in the chain has been chosen as a header. The rest of the sensor nodes can possess cooperative communication along the route. With a great mobility among the sensor node the route may be weakened. The delay due to the far sensor node is the main limitation of this topology.

**Cluster Based Topology:** The sensor nodes are grouped together as a cluster by means of some constraint and a cluster head is been chosen. That header node will gather the information from each individual of the group and transmit the collected information to the sink. This method has been accomplished in two stages and they are setup stage and steady state stage. In the setup stage, the cluster head selection is performed either by concentrated or circulated cluster head selection calculation. The steady state is performed
on the basis of primary stage in which the information has been disseminated to the sink node. Moreover, the partition of the network into clusters creates sub-optimal routes from the source node to multicast cluster members and unbalanced utilization of energy around Access Points (APs).

**Tree Based Topology**: The deployed sensor nodes have been constructed in a logical tree like structure. The optimal route has been built by the spanning mechanism like Breadth First Search and Depth First Search. The data gathered from the sensors at the base is transmitted to the sink by the tree traversing structure. This avoids flooding of packet traversing in the network. This topology aids in minimum power consumption. The drawbacks of the tree based topology are low cost efficiency and node failure.

**Cluster Tree Topology**: Cluster tree topology selects one node as a cluster head namely Designated Device that contains a high power for transmission and receiver affectability. The beacon packet consists of Network identity, cluster identification and node identification which are members of the designated node. Subsequently, the request and the response of the connection are used to build a cluster tree and this relies upon the reception of the beacon packet from a nearby sensor node. Moreover, the creation of cluster tree topology with the node identification is a challenging task, as the designated device should begin with the cluster tree creation. The foremost aim of the cluster tree is to minimize the energy utilization, end to end delay and better capacity of WSNs. Cluster tree topology is a hybrid method and it is identified that it can provide a better performance than other topologies. The cluster tree topology schemes like Cluster-Tree Data Gathering Algorithm and Cluster Independent Data collection Tree fail to preserve the data traffic, data rate, tree intensity, cluster dimension and coverage distance, of the tree structure. Hence this research work proposes an Energy Efficient Link aware Cluster Tree based algorithm for finding optimal path.
4.3 MOTIVATION

The flat topology is considered as static WSNs and here no predesigned topology exists to transmit the data from the sensor nodes to the sink. Here, every node communicates directly with the sink node or transmits the data packet simply to the immediate neighbor nodes and finally arrive at the sink node. This technique contains the drawbacks like node failure, delay, data redundancy and high energy consumption, as it involves in gossiping, flooding and direct communication, etc., to cooperatively communicate among the nodes and hence it is not suitable for WSNs.

The Chain topology offers improved performance than flat topology. Moreover, it increases the time during data collection. As, it needs to possess the chain path to arrive at the sink node, the intermediate or header nodes along the chain route aggregates the collected data from the predecessors node and the whole network dissipates the energy slowly because of the energy dissipation is even on WSN. Since the chain topology provides an enhanced performance than flat topology, it also contains disadvantages like node failure, delay and energy utilization. Due to such demerits in chain topology, this is not recommended for WSN.

The cluster based data gathering provides an improved performance with the chosen cluster heads. Moreover, the dissemination of data from cluster head to successor cluster head or sink node needs stable links that leads to excess energy utilization. In the scenario of data aggregation, it offers improved performance than flat, chain and tree topologies. The frequent change in cluster head due to excess energy consumption in header node leads to route failure which minimizes the network lifetime.
Tree based topology can minimize the energy utilization than chain and cluster topology. It consists of excess time stamps so as to gather the information from the leaf to root node. In harsh surroundings, it results in route failure, delay and packet drop. It is experimental that the hybrid topology can provide an improved performance than the single topologies.

Cluster Tree topology is a hybrid one and it can provide improved performance than other topologies. Moreover, the selection of cluster head and cluster maintenance under the harsh environment is a tedious task. To overcome the limitation of the existing protocols such as transmission coverage, energy consumption, connection time, RSS, throughput, delay and network lifetime, an Energy Efficient Link aware Cluster Tree based algorithm for finding optimal path (EELCT) is proposed.

4.4 NEED FOR CLUSTER TREE TOPOLOGY IN WIRELESSHART SENSOR NETWORK

The topology of the WirelessHART sensor network plays a vital role in efficiency of WSNs. Implementing a WirelessHART network is not a difficult task. The limited types of devices and self-organizing mesh capabilities take much of the guesswork out of the execution, but the technology has some limitations as the network grows. Larger networks will logically have devices that need more “hops” through the mesh to get data back to the host. As the number of hops increases, so does latency. Large Networks will have large number of devices that need more hops to reach gateway and are difficult to manage. Bottlenecks in the mesh become more likely, and a node failure there can bring down a large portion of the network as depicted in Figure 4.1.
Creating a clustered network is one solution. This can be done by breaking the larger networks into smaller ones, or clusters which reduce overall latency because nodes need to travel only fewer hops and this achieves reliable networks with no bottleneck. By eliminating bottlenecks and high demand routers, a battery-powered device is also reduced, resulting in less maintenance. Hence there is a need to develop cluster tree based algorithm for data gathering, as it is the best for energy efficiency among clusters in order to improve the network lifetime as illustrated in Figure 4.2.
4.5 ENERGY EFFICIENT LINK AWARE CLUSTER TREE BASED ALGORITHM (EELCT) FOR DATA GATHERING IN WSN

The proposed EELCT is composed of 3 stages such as: Cluster head election, Cluster tree hierarchy formation and optimal path selection. Initially the clusters have been formed with cluster head selection by considering the RSS, coverage time, connection time and connection accuracy and then the data collection tree has built in order to determine the feasible route between member and the sink. It is specified in intra cluster and DGT communication. Finally, the collected data is transmitted from the cluster members to the sink node. The architecture of the overall process is shown in the Figure 4.3 and data is disseminated from cluster head to CN and from that node to next CN. This process continues till the sink node is reached.
Initially the beacon signal has been used to identify the position of the sensor node. Once the neighbor nodes are determined, the cluster head election algorithm is used to elect the cluster head. Cluster head selection is based on the threshold value, received signal strength and coverage distance. The threshold value relies upon the degree of the neighbor nodes, remaining energy and present transmission distance. The node, which has maximum number of cluster members, higher residual energy and receives signal strength, has the possibility of being elected as cluster head by NM. CH advertises its status to the nearby nodes and requests to reply with their current energy status. During cluster formation, CH receives Residual energy from each cluster members and constructs its own neighboring table. After the cluster head election, the next phase of Cluster Tree formation is initiated which connects cluster head and sink.
The threshold value $T_v$, is calculated using total number of cluster members, residual energy, current coverage distance of the sensor node and Flag value $F_{CH}$, which is defined as the boolean value which checks whether the selected node has been the cluster head before or not. Consider $F_{CH} = 1$ for previous round cluster head and $F_{CH} = 0$ for sensor node having a chance to act as current round cluster head based on threshold value. $N_c$, is the number of cluster members in the CH, $N_m$ is the Maximum number of cluster members, $E_c$ is the current sensor node energy, $E_m$ is the initial sensor node energy, maximum coverage radius $R_m$ and current Coverage radius $R_c$. Those nodes having maximum number of cluster members, residual energy, RSS and robustness can be elected as cluster head and is given by

$$T_v = F_{CH} + \left( \frac{N_c}{N_m-N_c} \times \frac{E_m-E_c}{E_m} \times \frac{R_m-R_c}{R_m+R_c} \right)$$  \hspace{1cm} (4.1)$$

The distance between the cluster head and the cluster member is given by $[D_{cs}]$, then the equation is given as

$$[D_{cs}(t)]^2 \geq [(X_{ch} - X_s)^2 - (Y_{ch} - Y_s)^2]$$  \hspace{1cm} (4.2)$$

Where $(x,y)$ is the primary node location. Then, subscript $(ch, s)$ corresponds to cluster head and sensor node.

The received signal strength $(R_{SC})$ is given by

$$R_{SC} = R_{SC}^c - R_{SC}^m$$  \hspace{1cm} (4.3)$$

Where $R_{SC}^c$ – current threshold value,

$R_{SC}^m$ – minimum required threshold value

If the value is positive, the cluster members join in an appropriate cluster and communicate with appropriate cluster head.
4.5.2 Cluster Tree Hierarchy

NM elects few nodes as Collector Nodes (CN) to generate Data Gathering Tree (DGT). The DGT formation is based on the current location of CH, robustness, received signal strength and coverage distance. Each Cluster may have more than one CN which is assigned using one-hop distance nodes, making sure it is not a cluster head. The data flow from the CH to CN and from CN to Gateway or through another CN is known as DGT.

The intra cluster communication and inter cluster communication is achieved before the cluster tree hierarchy formation is done. The intra cluster is the communication within the cluster, that is CH election and data transfer between the cluster members and CH is established. The inter cluster communication is between the clusters, that is two or more clusters. Here the inter cluster is established using an intermediate sensor called CN. The Gateway sends signals to the sensor nodes. The received signal is utilized to assign CN. The CN is assigned using one-hop distance nodes from sink, making sure it is not a cluster head and the CN has the capability to collect data from the cluster head. For that the CN must be in the reach of the nearby cluster heads, higher coverage distance and higher residual energy. The CN in that particular round of data transmission does not sense data but its only job is to collect data from the cluster head and transmit it to sink through another CN or directly to sink. The DGT development calculation is executed by the sink with a specific end goal to choose the DGT to shape a free tree structure. In CN correspondence stage, the sink chooses the primary CN in view of the threshold value, association distance, traffic.

DGT construction for the single cluster is shown in Figure 4.4. Here the CH has an opportunity to join with the CN-13, CN-14 and CN-15. Be that as it may, the CH selects a CN with better coverage distance,
robustness and less traffic (i.e., CN-13). Moreover, the DGT grow its tree structure with the assistance of CN.

![DGT Construction for single cluster](image)

**Figure 4.4 DGT Construction for single cluster**

The algorithm for the DGT construction is given below.

**Algorithm steps:**

Step 1: Declare the variables such as Sensor Nodes (SN), Gateway (BS).

Step 2: Beacon signal is passed from sink (GW) to sensor nodes.

Step 3: Received Signal Strength (RSS) is calculated to know the position of the sensor node.

Step 4: Other values are calculated such as Residual Energy (RE), Coverage Distance (CD) and Data Packet Ratio (DPR).

Step 5: Assign the amount of data packets by each Field Devices to be transmitted to the Cluster Head (CH).

Step 6: Select the CH based on threshold value.

Step 7: Traverse one hop distance from gateway to elect CN.

Step 8: Node Identity (NI)-one hop from sink/CN is identified and if (NI! =CH) then SN=CN.
Step 9: Check if CD (SN)\(\geq\)CH and coverage area (CA) of CH has not more than 2 CN then elect SN as CN.

Step 10: Define array Path To Sink, PTS \([\cdot]\). The possible path to sink is chosen as element to PTS [SN-CH-CN1-BS, SN-CH-CN2-BS].

Step 11: Optimal path from PTS \([\cdot]\) array is chosen with threshold value.

Step 12: if threshold value of PTS [CN1]\(>\)PTS [CN2] choose PTS [CN1].

Step 13: Paths of PTS \([\cdot]\) == CTH (Cluster Tree Hierarchy).

4.5.3 Data Communication Using Optimal Path

The Cluster tree hierarchy is a tree formation topology in which the CNs and CHs form the leaf node. The parent node is Gateway. The routing of data from cluster member to Gateway/sink is selected from various possible routes as optimal path. The optimal path chooses which data collector is important to reach the sink. The cluster head can have two one hop distanced CNs. The best possible CN is required to select the path to reach the destination. The CN is selected based on the following criteria: higher residual energy, present load route, and distance and communication range.

4.6 PERFORMANCE EVALUATION

4.6.1 Performance Metrics

In this section, performance of the existing algorithms under various parameter settings via simulations is presented. The Performance of EELCT is compared with existing algorithms, according to the following metrics.

Delay (ms): The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations. It is an average time taken by the packets
to pass through the networks. If the value of end-to-end delay is high then it means that the network is congested.

\[
Delay = \sum_{0}^{n} \frac{Pkt \ Recvd \ time - Pkt \ Send \ time}{Time}
\]

**Packet Delivery Ratio (%)**: It is the ratio of the number of packets received successfully and the total number of packets transmitted.

\[
Packet \ delivery \ ratio = \frac{Number \ of \ all \ packets \ received \ at \ sink}{Number \ of \ all \ packets \ generated \ at \ sensor \ nodes}
\]

**Energy Consumption (Joules)**: It is the average energy consumption of all nodes in ending, receiving and forward operations.

**Throughput (Mbps)**: It is defined as the average rate of successful packet delivery per unit time over a communication channel. Frequent topology changes, unreliable communication, limited and width and limited energy are the factors that affect throughput. The throughput is measured in bits per second (bit/s or bps).

\[
Throughput = \sum \frac{Data \ packets \ Received}{Transmission \ time}
\]

**Data Packet Loss**: It is defined as the difference between the numbers of packets sent by the source and received by the destination. Lowering the packet-loss betters the performance of the protocol. A packet is dropped when the buffer is full.

\[
Data \ packet \ loss = \frac{Total \ Packets \ Received}{Total \ Packets \ Sent}
\]
Network lifetime(s): Network lifetime is defined as the time until the first node or group of nodes runs out of energy. Alternatively the network lifetime is defined as the time duration from the launch of the sensor network to the instant when some of the targets are not covered by certain number of sensor nodes.

4.6.2 Simulation Settings

In this section, performance of the existing algorithms under various parameter settings via simulations is presented. A WSN system comprising of 100-500 nodes is used in the scenario. All the nodes were randomly deployed in a square region of $1000 \times 1000 \text{ m}^2$; assume that the initial energy of each sensor node is 2 Joules enabling a sensor to operate. The MAC type used here is IEEE 802.15.4 WirelessHART Standard. The size of the data packet is 133 bytes including header. The transmission range with in the cluster is set as 40m and the transmission distance of each node is 50m. Communication energy parameters can be set as $E_{elec} = 50 \text{ nJ/bit/m}^2$ and $E_{amp} = 0.0013 \text{ pJ/bit/m}^4$. Energy required for data aggregation is 5nJ/bit/Signal.

4.6.3 Simulation Results

This section presents the simulation results of EELCT with respect to several parameters. The parameters used for performance evaluation are energy consumption, packet delivery ratio, delay, and throughput and packet loss ratio. The performance of the proposed approach is compared with two algorithms, namely, LEACH and CTDGA.

Figure 4.5 and Table 4.1 clearly indicate that EELCT algorithm is able to achieve better throughput when compared with existing schemes. This may be attributed to two salient features of the EELCT. First, it offers
minimum load with in the cluster and cluster to cluster communication. Second, EELCT avoids unwanted control packets flooding because DGT selects an optimal path between CH and sink.

Table 4.1 Throughput vs Number of nodes

<table>
<thead>
<tr>
<th>Number of nodes</th>
<th>LEACH</th>
<th>CTDGA</th>
<th>EELCT (Proposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.825</td>
<td>0.845</td>
<td>0.9</td>
</tr>
<tr>
<td>200</td>
<td>0.815</td>
<td>0.839</td>
<td>0.886</td>
</tr>
<tr>
<td>300</td>
<td>0.78</td>
<td>0.8295</td>
<td>0.872</td>
</tr>
<tr>
<td>400</td>
<td>0.764</td>
<td>0.8215</td>
<td>0.865</td>
</tr>
<tr>
<td>500</td>
<td>0.749</td>
<td>0.8132</td>
<td>0.8543</td>
</tr>
</tbody>
</table>

Figure 4.5 Throughput vs Number of nodes

Figure 4.6 and Table 4.2 shows Performance of delay with respect to total number of sensor nodes. Here 100-500 nodes are selected to
investigate the performance of delay over the network. The simulation results show that proposed technique has minimum delay when compared to existing algorithms because it offers the shortest path and also provides a stable link which reduces packet drop ratio and packet retransmissions over the network.

Table 4.2 Delay vs Number of nodes

<table>
<thead>
<tr>
<th>Number of nodes</th>
<th>LEACH</th>
<th>CTDGA</th>
<th>EELCT (Proposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>6.02</td>
<td>4.034</td>
<td>2.157</td>
</tr>
<tr>
<td>200</td>
<td>7.034</td>
<td>5.04</td>
<td>2.225</td>
</tr>
<tr>
<td>300</td>
<td>8.254</td>
<td>6.12</td>
<td>2.556</td>
</tr>
<tr>
<td>400</td>
<td>9.124</td>
<td>7.045</td>
<td>2.785</td>
</tr>
<tr>
<td>500</td>
<td>9.943</td>
<td>8.214</td>
<td>3.004</td>
</tr>
</tbody>
</table>

Figure 4.6 Delay vs Number of nodes
Figure 4.7 and Table 4.3 illustrates the performance of number of nodes and energy consumption. EELCT selects CH with better threshold value, RSSI and robustness thereby reducing the convention time and control packet overhead, and RSSI is also maintained.

**Table 4.3 Energy vs Number of Nodes**

<table>
<thead>
<tr>
<th>Number of nodes</th>
<th>LEACH</th>
<th>CTDGA</th>
<th>EELCT (Proposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.25</td>
<td>0.17</td>
<td>0.05</td>
</tr>
<tr>
<td>200</td>
<td>0.261</td>
<td>0.179</td>
<td>0.074</td>
</tr>
<tr>
<td>300</td>
<td>0.271</td>
<td>0.212</td>
<td>0.085</td>
</tr>
<tr>
<td>400</td>
<td>0.29</td>
<td>0.246</td>
<td>0.123</td>
</tr>
<tr>
<td>500</td>
<td>0.358</td>
<td>0.287</td>
<td>0.134</td>
</tr>
</tbody>
</table>

**Figure 4.7 Energy vs Number of nodes**
From Figure 4.8 and Table 4.4, the network lifetime obtained by EELCT is the longest. The main reason is that proposed approach uses clusters and tree to gather and transmit data, which can balance the energy consumption among nodes and efficiently use energy.

Table 4.4 Network Lifetime vs Number of nodes

<table>
<thead>
<tr>
<th>Number of nodes</th>
<th>LEACH</th>
<th>CTDGA</th>
<th>EELCT (Proposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>500</td>
<td>940</td>
<td>1000</td>
</tr>
<tr>
<td>200</td>
<td>640</td>
<td>950</td>
<td>1032</td>
</tr>
<tr>
<td>300</td>
<td>625</td>
<td>1000</td>
<td>1065</td>
</tr>
<tr>
<td>400</td>
<td>635</td>
<td>1050</td>
<td>1102</td>
</tr>
<tr>
<td>500</td>
<td>647</td>
<td>1100</td>
<td>1157</td>
</tr>
</tbody>
</table>

Figure 4.8 Network lifetime vs Number of nodes
When a node depletes its energy, it will result in the network partition. Network lifetime is the time when the first node depletes its energy. Thus, the scheme greatly contributes to prolonging the network lifetime. EELCT can conserve the sensor node residual energy, prolong the network lifetime and network reliability.

**Table 4.5 Packet Delivery Ratio vs Number of nodes**

<table>
<thead>
<tr>
<th>Number of nodes</th>
<th>LEACH</th>
<th>CTDGA</th>
<th>EELCT (Proposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>95</td>
<td>96.5</td>
<td>99.5</td>
</tr>
<tr>
<td>200</td>
<td>93.35</td>
<td>95.12</td>
<td>99.21</td>
</tr>
<tr>
<td>300</td>
<td>89.56</td>
<td>93.012</td>
<td>99.015</td>
</tr>
<tr>
<td>400</td>
<td>88.67</td>
<td>92.25</td>
<td>98.865</td>
</tr>
<tr>
<td>500</td>
<td>86.54</td>
<td>91</td>
<td>98.63</td>
</tr>
</tbody>
</table>

**Figure 4.9 Packet Delivery Ratio vs Number of nodes**
Figure 4.9 and Table 4.5 shows the performance of EELCT algorithm with CTDGA and LEACH in terms of packet deliver ratio. It may be noted that the proposed algorithm achieves better performance than existing algorithm because EELCT is able to provide considerably stable links which reduces the packet overhead of the cluster head and select the stable links based on threshold value.

**Table 4.6 Data Packet Loss vs Number of nodes**

<table>
<thead>
<tr>
<th>Number of nodes</th>
<th>LEACH</th>
<th>CTDGA</th>
<th>EELCT (Proposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>40</td>
<td>38</td>
<td>32</td>
</tr>
<tr>
<td>200</td>
<td>40</td>
<td>42</td>
<td>33</td>
</tr>
<tr>
<td>300</td>
<td>47</td>
<td>42</td>
<td>35</td>
</tr>
<tr>
<td>400</td>
<td>50</td>
<td>46</td>
<td>38</td>
</tr>
<tr>
<td>500</td>
<td>52</td>
<td>54</td>
<td>40</td>
</tr>
</tbody>
</table>

**Figure 4.10 Data Packet Loss vs Number of nodes**
Observation from Figure 4.10 and Table 4.6 indicates that the data packet loss ratio is minimal in EELCT when compared with existing algorithm. The x-axis is Number of nodes and y-axis being percentage of data packet loss from overall network.

4.7 SUMMARY

This chapter presented an Energy Efficient link aware Cluster Tree based data gathering algorithm for data gathering to facilitate better Quality of service (QoS) with respect to network lifetime for Industrial based WSNs using WirelessHART standard. Topology management plays a vital role in reducing various constraints such as limited energy, node failure, long-range communication within a network, communication failure, delay, traffic, etc. EELCT integrates the advantage of both cluster and tree. Cluster tree topology is a hybrid method, and it is identified that it can provide a better performance than other topologies. EELCT is proposed for WSNs to exploit the Network lifetime, residual energy, and RSS, throughput, PDR and stable link for sensor nodes whereas NM chooses CH with maximum threshold value and coverage distance. Similarly NM or CN elects the one hop neighbor CN or CH with maximum threshold value, RSS and with less traffic. The strength of EELCT algorithm is to construct simple tree structure, thereby reducing the energy consumption of the cluster head and avoiding frequent cluster formation. From the Simulation results, it is shown that EELCT provides more stable links, better throughput, lower energy consumption and longer network lifetime than conventional algorithms.

However packets may drop once if the cluster tree loses its energy to transmit data packets Hence, Efficient Load balancing algorithm is incorporated with EELCT and is elaborated in the next chapter.