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Energy Efficient Clustering Method for Wireless Sensor Networks

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Abstract: Aiming at the problem of limited energy of sensors in Wireless Sensor Network, based on the classic clustering routing algorithm LEACH, a distance-energy cluster structure algorithm considering both the distance and residual energy of nodes is presented, which improves the process of cluster head election and the process of data transmission. This protocol can successfully prolong the network's lifetime by 1) reducing the total energy dissipation on the network and 2) evenly distributing energy consumption over all sensor nodes. In this protocol, the nodes with more energy and less distance from the BS are probable to be selected as cluster-head. Simulation results with MATLAB show that proposed protocol could increase the lifetime of network more than 90% for First Node Die (FND) and more than 6% for the half of the nodes alive (HNA) factors as compared with conventional protocols.

Key words: Clustering methods . energy efficiency . routing protocol . wireless sensor networks

INTRODUCTION

Wireless Sensor Network [1] is one of the three major high-tech industries in the future of the world which is consisted of a set of wireless sensor nodes according to a certain communications and topologies protocol. It has been widely utilized in the military, environmental monitoring, dysfunction diagnosis and the medical measurement [2-4]. As its broad application prospects and great application values, it has become one of the hot research topics. Due to small size of a sensor node, sensor networks are constraint by limited power, limited communication capabilities, limited processing power and limited memory [5].

Communication protocols highly affect the performance of WSNs by an evenly distribution of energy load and decreasing their energy consumption and thereupon prolonging their lifetime. Thus, designing energy-efficient protocols is crucial for prolonging the lifetime of WSNs [6]. Among the proposed communication protocols, hierarchical (cluster based) ones have significant saving in the total energy consumption of wireless micro sensor network [7, 8]. In these protocols, the sensor nodes are grouped into a set of disjoint clusters. Each cluster has a designated leader, the so-called cluster-head (CH). Nodes in one cluster do not transmit their gathered data directly to the BS, but only to their respective cluster-head. Accordingly, the cluster-head is responsible for: 1) coordination among the cluster nodes and aggregation of their data and 2) transmission of the aggregated data to the BS, directly or via multi-hop transmission. Each sensor only belongs to one cluster and communicates with the BS only through the cluster header node in the cluster. Creation of clusters and assigning special tasks to cluster-heads can greatly contribute to overall system scalability, lifetime and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion to decrease the number of transmitted messages to the BS.

Till now, several cluster-based protocols have been proposed for wireless sensor networks (Leach [9, 10], Teen [11], Apteen [12], DBS [13], EMPAC [14], FTPASC [15], SOP [16]), in them, residual energy and nod's distance from BS in clustering process have not been considered. For this reason, these protocols couldn't distribute energy load in the network well. In this paper we use the present hierarchical protocols and especially LEACH protocol. By considering residual energy and distance parameters in clustering process, an energy-efficient communication protocol with the maintenance of the network's scalability is presented. In this protocol, like [13], we divide the whole network to concentrate circuit segments around BS; the closer the segment to the BS, the more the number of its CHs. On the other hand, between each segment's nodes, those who have more energy have the stronger possibility for becoming CH.

The remainder of this paper is organized as follows: A brief introduction of LEACH protocol is presented in Section 2. In Section 3, we introduce some preliminary notions concerning the proposed protocol. Section 4 describes the design of our novel protocol in detail. Simulation and results are discussed in Section 5. Finally, conclusions are made in Section 6.

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RELATED WORKS

The LEACH protocol is one of the most popular hierarchical routing algorithms for sensor networks [9, 10]. Basically, LEACH is a dynamic clustering method. In this method, time is partitioned into fixed intervals with equal length, which is called topology update interval or round here. At the beginning of each interval, each sensor becomes a Cluster Head (CH) with some predefined probability. The cluster heads then broadcast messages to their neighbors. Other sensors receive messages and join a cluster by choosing the nearest cluster head (strongest signal). During the interval, Cluster Members (CM) send information to their cluster head. The cluster heads aggregate, compress and route the information towards the remote access point. Once the interval ends, the whole topology construction procedure restarts. Hence, the clusters and cluster heads are not fixed. The threshold is set as follows:

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod \frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

where P is the desired percentage to become a cluster-head, r is the current round and G is the set of nodes that have not being selected as a cluster-head in the last 1/p rounds. After the cluster-heads are selected, the cluster-heads advertise to all sensor nodes in the network that they are the new cluster-heads. And then other nodes organize themselves into local clusters by choosing the most appropriate cluster-head (normally the closest cluster-head). During the steady-state phase the cluster-heads receive sensed data from cluster members (according to TDMA schedule that was created and transmitted to them) and transfer the aggregated data to the BS. This algorithm ensures that every node becomes a cluster-head exactly once within 1/P rounds, that we call this number of rounds as epoch in this paper.

Multi-hop routing [17, 18] two-Level hierarchy LEACH (TL-LEACH) [15]: are proposed as extension to the LEACH algorithm. It utilizes two levels of cluster heads (primary and secondary) in addition to the other simple sensing nodes. In this algorithm, the primary cluster head in each cluster communicates with the secondaries and the corresponding secondaries communicate with the nodes in their sub-cluster. The two-level structure of TL-LEACH reduces the amount of nodes that need to transmit to the sink, effectively reducing the total energy usage.

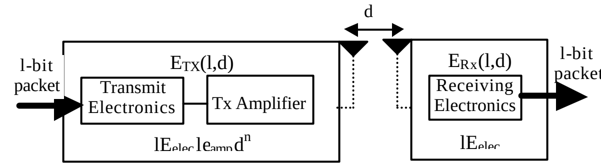

Fig. 1: Radio energy dissipation model

Therewith, simulation results in [19] show that multi-hop schemes outperform current hierarchical protocols only in the presence of the sensor nodes equipped with enhanced transceiver circuits that consume less than 50 nJ to receive one bit of the data packet. therefore, in this paper as in [10-15] the multi-hop approach is not utilized for transmitting data to the BS and the cluster heads directly communicate with the BS.

PRELIMINARIES

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.

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 [20]. Power control can be used to invert this loss by appropriately setting the power amplifier if the distance is less than a threshold, the free space (f_s) model is used; otherwise, the multipath (mp) model is used. Thus, to transmit an l-bit message a distance, the radio expends:

$$E_{TX}(l,d) = E_{TX-elec}(l) + E_{TX-amp}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, d < d_0 \\ lE_{elec} + l\varepsilon_{mp}d^4, d > d_0 \end{cases} \quad (2)$$

and to receive this message, the radio expends:

$$E_{Rx}(l) = E_{Rx-elec}(l) = E_{elec} \quad (3)$$

The electronics energy, E_{elec}, depends on factors such as the digital coding, modulation, filtering and spreading of the signal whereas the amplifier energy, $\varepsilon_{fs}d^2$ or $\varepsilon_{mp}d^4$ depends on the distance to the receiver and the acceptable bit-error rate.

According to the radio energy model described previously, in [10] the optimum number of clusters k_{opt} for a cluster-based network that uses LEACH communication protocol and contains N sensor nodes distributed uniformly in an M * M region has been calculated as:

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}\frac{M}{d_{toBS}^2} \quad (4)$$

where, d_{toBS} is the distance from the cluster-head node to the BS.

Assume that there are nodes uniformly distributed throughout the (M×1 region, "half of the nodes alive" factor has been driven in continue. If there are clusters in the network [10], in average there are nodes in each cluster, one node act as cluster-head and (N/K-nodes as the non-clusterheads, each cluster head node dissipate energy for receive the data sent by non-cluster head nodes, aggregate received data and transmitting the aggregated data to the BS. In [10] the energy dissipated by each cluster-head explained as follow:

$$E_{CH} = lE_{elec}(\frac{N}{K}-1) + lE_{DA}\frac{N}{K} + lE_{elec} + l\epsilon_{mp}d_{to}^4 \quad (7)$$

And the energy dissipated by each non-CH node is:

$$E_{non-CH} = lE_{elec} + l\epsilon_{fs}d_{toCH}^2 \quad (5)$$

where is the number of bits in each data message, d_{to} and d_{to} are the distances from the node to the base station and to the cluster-head respectively, we consider both square by width and circle by radius , shaped region for the network and we assume nodes are uniformly distributed throughout the network with distribution function ρ(x,. Because of uniformly distribution nature of the nodes then $\rho = \overline{\pi}$ for circle shaped and ρ = for square shaped networks. The square distance from the nodes to the base station is given by

$$E[d_{toBS}^2] = \iint (x^2+y^2)\rho(x,y)dxdy \quad (6)$$

Equation (6) can adopted for circle shaped as

$$E[d_{toBS}^2] = \int_0^{2\pi}\int_0^R r^3\rho(r,\theta)drd\theta = \int_0^{2\pi}\int_0^R r^3\frac{1}{\pi R^2}drd\theta = \frac{1}{2}R^2 \quad (7)$$

And it can be adopted for square shaped as

$$E[d_{toBS}^2] = \int_0^M\int_0^M (x^2+y^2)\frac{1}{M^2}dxdy = \frac{2}{3}M^2 \quad (8)$$

Substituting the d_{to}^2 obtained by Eqs(7) and (8) in Eq(4) conclude the optimal number of clusters in the networks, the average number of nodes in each cluster is $\overline{K}_4$ and hence each node act as cluster head once every $\overline{K}_4$ rounds (we call these number of rounds as epoch), so the total energy dissipated in network during an epoch is given by

$$E_{epoch} = (\frac{N}{K_{opt}} - 1)E_{non-CH} + 1E \quad (9)$$

The expected number of epochs for "half of the nodes alive" factor is represented by T_H and:

$$E[T_{HNA}] = \frac{E_{initial}}{E_{epoch}} \quad (10)$$

In continue we use this factor to evaluate the performance of proposed clustering protocol.

PROPOSED PROTOCOL

A potential problem with LEACH is that all cluster-heads send the compressed data to the BS directly. If all sensor nodes are pervasive in a large area, some clusters are far from the BS and others are close to the BS. This can lead to great difference between the transmission energy dissipations that the nodes use to transmit data to the BS. The radio transmission energy dissipation includes two parts of radio electronics energy and power amplifier energy. Generally the amplifier energy required for a successful transmission is much larger than the radio electronics energy and dominates the transmission energy dissipation. According to the free space channel model, the minimum required amplifier energy is proportional to the square of the distance from the transmitter to the destined receiver ($E_{Tx-amp} \propto d^2$) [15]. So the transmission energy consumption will increase greatly as the transmission distance rises. Therefore after the network operates for some rounds there will be considerable difference between the energy consumption of the nodes near the BS and that of the nodes far from the BS. The nodes far from the BS will use up their energy before those near the BS. As a result the network will be partitioned into regions with live nodes and dead nodes and the performance of the network will decline. Figure 2 shows the simulation result after 600 rounds on LEACH protocol. For this simulation we use a 200-nodes randomly scattered throughout a 400m×400 rectangular area and the base station located at (200,200). As shown in the Fig. 1 the network is partitioned into two regions, live region

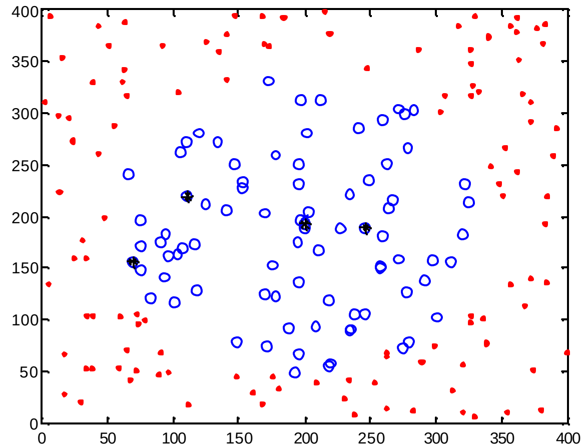

Fig. 2: Dead and alive nodes after 600 ran LEACH algorithm

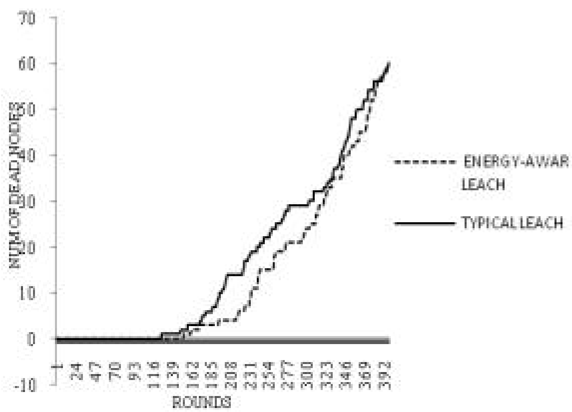

Fig. 3: Number of dead nodes in energy-efficient leach and typical leach

which is the central with the closest nodes to the base station and the dead region which is the outward with the far nodes from the base station.

The proposed approach in [13] divides the entire network into equal-area segments and applies different clustering policies to each segment. We use this idea to prevent unbalanced energy consumption among sensor nodes caused by difference of distance from the nodes to the BS.

The second problem of the LEACH is that in this protocol nodes are absolutely chosen accidentally. Because cluster heading consumes a lot of energy from a node, if a node which is chosen has a few energies, this residual energy is finished faster and node dies. This matter causes to the removal of balance of the network's energy load [13]. It is useful to use of an energy-aware factor while selecting CHs, a common energy-aware metric for wireless sensor networks is the nodes residual energy toward its initial energy:

Table 1: Simulation results for different threshold used in leach

	Factor		
Threshold	First node die (round)	Number of data packets sent to BS	Number of dead nodes
Energy-aware	153	5053	120
Typical leach	131	4516	139

$$F_{energy\ \ aware} = \frac{E_{resid}}{E_{initial}} \quad (11)$$

With the use of this energy-aware factor nodes with little remaining energy are unlikely to be used as CH consequently this increases the time before the first nodes die [21]. By using this factor the threshold explained in Equation 1 can be modified as follow:

$$T(n)_{new} = \frac{p}{1 - p\left(r \bmod \frac{1}{p}\right)} \times \frac{E_{resid}}{E_{initial}} \quad (12)$$

Figure 3 shows the number of dead node in energy-aware leach and typical leach over network rounds. It can be seen that the energy-aware leach has the better performance than the typical leach. From this plot and the result summarized in Table 1 we can see the lifetime before the first node die and the total number of dead nodes are better in energy-aware leach in respect to typical leach.

Inasmuch the amount of data packets received at BS can be considered as a factor for estimate the networks quality of service, we compare the data packet sent by both Energy-aware and typical leach, the more data the BS receives, the more accurate its view of the remote environment will be.

To solve the preceding problems, we propose a novel protocol. This protocol considers the residual energy and distance from the BS of each node in the cluster-head selecting process, hence the nodes with the less energy than the other nodes and the nodes with more distance from the BS have the smallest chance to be selected as a cluster-head for current round. In this protocol, we divide the whole of the network's terrain into concentric circular segments around the BS and the number of cluster-heads in each segment is different from the other segments in terms of distance from the BS. In closer segments the probability of becoming CHs is more than distant segments and thus the number of cluster-heads in these segments is more, on the other hand between each segment's nodes, those who have more energy have the stronger possibility for becoming CH. it is assumed that nodes are aware of their approximate distance from the BS, so that the sensor

Table 2: Parameters values used in the simulation

Parameters	Experiment 1 (BS is inside)	Experiment 2 (BS is outside)
Network Span	(0,0) to (350,350)	(0,0) to (200,200)
N	200	200
Do	87.7m	87.7m
Bs Position	(175,175)	(100,300)
E_{elec}	50 nJ/bit	50 nJ/bit
ε_{fs}	10pJ/bit/m^2	10pJ/bit/m^2
ε_{mp}	0.0013pJ/bit/m^4	0.0013pJ/bit/m^4
Number of Time Frames Per Round	1	1
Round Duration Time	20s	20s
E_{DA}	5nJ/bit/signal	5nJ/bit/signal
Initial Energy of Each Node	0.5J	0.5J
Packet Size	500 bytes	500 bytes
Number of Segments	3	3

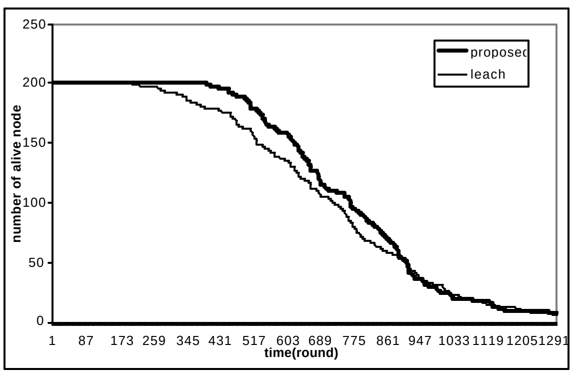

Fig. 4: System lifetime using LEACH and our scheme in the first experiment

nodes can guess the segment they belong. In [22], signal strength parameter has been used for approximating the distance parameter. Assuming that the innermost segment has the lowest index, in the segment j, node i may become a cluster-head at round r (which starts at time t) with below threshold:

$$T(n) = \frac{p}{1-p\left(r \bmod \frac{1}{p}\right)} + \left(\frac{m+1}{2} - j\right) * \left[\left(\frac{E_{resid}}{E_{initial}}\right)^{\left(\frac{m+1}{2} - j\right)} + \left(\frac{r_s}{epoch}\right) \right] \quad (13)$$

In Equation.13, j is the segment number, m is the number of total segment in the network field, E_{resid} and $E_{initial}$ are current energy and initial energy of each node respectively and r_s is the number of consecutive rounds (in each epoch) in which a node has not been cluster-head. Thus, the chance of near to BS and high energy nodes to become CH increases because of a higher threshold. Additionally, r_s will be reset to 0 when a node becomes CH or when r_s reaches the value (epoch-1).

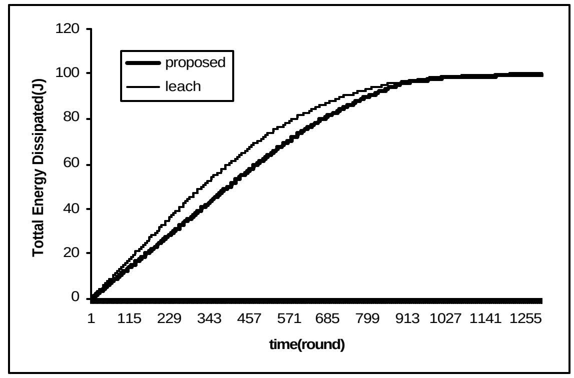

Fig. 5: Total energy dissipated in LEACH and our scheme in the first experiment

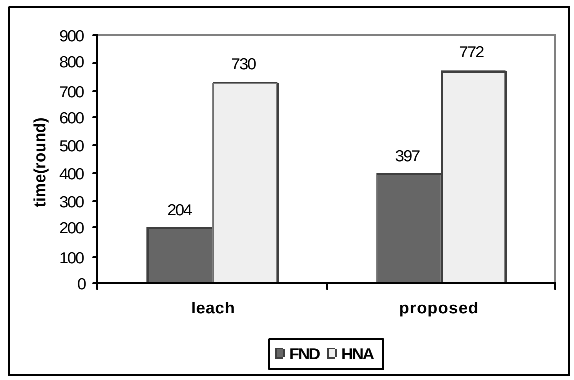

Fig. 6: Comparison of network lifetime using metrics FND and HNA between leach and our scheme in the first experiment

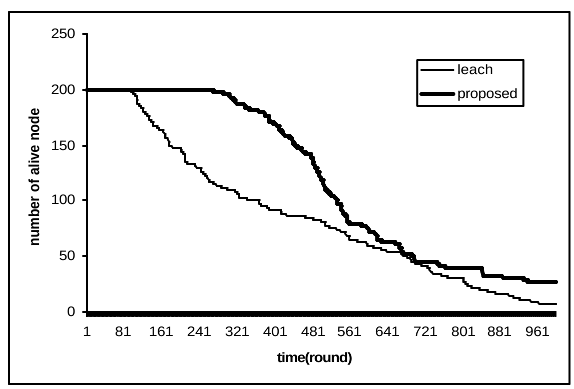

Fig. 7: System lifetime using LEACH and our scheme in the second experiment

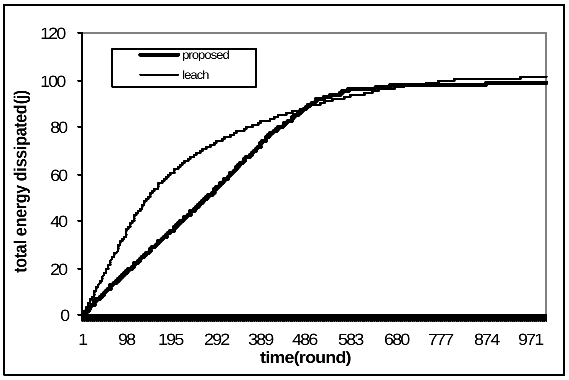

Fig. 8: Total energy dissipated in LEACH and our scheme in the second experiment

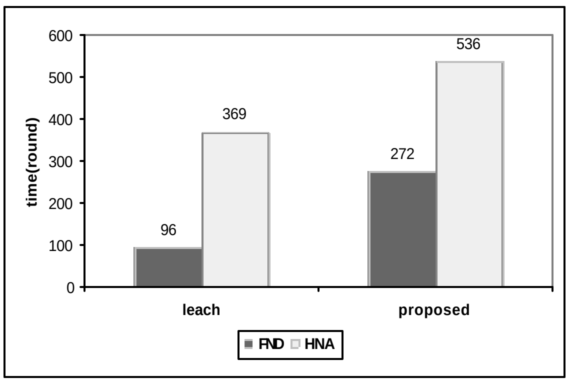

Fig. 9: Comparison of network lifetime using metrics FND and HNA between leach and our scheme in the second experiment

SIMULATION RESULTS

In this section, we evaluate the performance of the proposed approach through the simulations. A simulator is designed and implemented in MATLAB in order to investigate the efficiency of the mentioned protocols. We compare the proposed approach with LEACH. In our experiments, we consider two network topologies. The simulation parameters used in each experiment are shown in Table 2. For the first experiment nodes are randomly distributed between (x = 0, y = 0) and (x = 350, y = 350) with the BS at location (x =175, y = 175). Figure 3 and 4 show the total number of dead and alive nodes respectively over simulation time of 1100 rounds. It can be seen that nodes remain alive for a longer time in EDBC than LEACH. Note that further increasing of the number of segments from three does not improve the network lifetime considerably, so we did not increase the number of segments further. Figure 5 shows the total energy consumption of the network over simulation time. Based on simulation results, we find that an energy saving up to 15% is obtainable. Using two metrics, First Node Dies (FND) and Half of the Nodes Alive (HNA) proposed in [23], we exactly compare LEACH with EDBC in terms of network lifetime. Figure 6 illustrates that using our scheme can increase the lifetime of a microsensor network by 94% for FND and more than 6% for HNA.

For the second experiment nodes are randomly distributed between (x = 0, y = 0) and (x = 200, y = 200) with the BS at location (x =100, y = 300). The results of similar simulations to the first experiment for simulation time of 1000 rounds are depicted in Figure 7-9.

CONCLUSIONS AND DISCOSION

In this paper, an analytically model for performance evaluation factors in WSNs is derived and these factors have been used in order to assessing the performance of presented energy efficient clustering method and comparing it to the LEACH protocol. Results from our simulations show that the proposed protocol provides better performance for energy efficiency and network lifetime. However our protocol can be classified as a protocol with continuous data transfer just like LEACH, which in its general form is intended for static networks. With some modifications, our protocol can handle networks with some mobile nodes. Our protocol can still be improved further. For example, multi-hop routing algorithm can be implemented for all nodes in the network.

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