A Novel Approach for Energy-Efficient Communication in a Constrained IoT Environment

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***Abstract*—In the realm of the Internet of Things (IoTs) and wireless sensor networks (WSNs), two key concerns are improving security and energy efficiency. One approach to enhancing network longevity is through the implementation of clustering, which involves managing cluster heads. In this study, the authors proposed two variants of a novel algorithm for energy efficient communication in a constrained IoT environment. One variant considers the node degree while the other doesn't consider it to improve the round speed by eliminating mandatory re-election processes. Both variants also eliminate the selection of zero cluster heads problem, specifically at the beginning or towards the end of the network. Additionally, the authors tested the performance of proposed variants against several well known algorithms based on various factors such as operating nodes, number of clusters, transmission energy, remaining energy using MATLAB simulation environment. These comparisons will give us a crucial insight into the working of the proposed algorithm and question its applicability in the real world. The results of this comparison are promising, as the proposed variant with node degree outperforms other algorithms.**

***Index Terms*—IoT, Clustering, Cluster Head, Energy Efficiency, WSN, LEACH, LEACH-C, HEED.**

I. Introduction

A WSN consists of a large number of sensors or sensor nodes. So different sensors are used in IoT devices to collect and transmit data. Sensors continuously sense and send data about their surroundings and the condition of connected devices. A massive number of sensors are deployed in the physical environment to collect various parameters like temperature, humidity, moisture, location with the help of wireless networks to improve decisions with real time monitoring. These sensors have memory, power/energy, and computing capability constraints. A high degree of communication is there due to the real time monitoring, which increases energy consumption. Hence, battery depletion occurs frequently. Once the battery is depleted, the sensor fails to work. It leads to low network lifetime. Thus, it becomes challengeable to ensure reliable and sustainable energy supply to these sensor devices. Therefore, it is important to design an energy efficient mechanism for these resource constrained sensor devices in a smart system. Inspired by this premise, the authors present an algorithm that factors in efficiency when choosing cluster heads and assigning nodes to form a cluster. This paper is organized as follows in subsequent sections: Section II mentions the background and related work regarding some of the energy works. Afterwards, two proposed variants of algorithms along with ABPL (Average Backbone Path Length) and LSP (Longest Shortest Path) are described in section III. Section IV shows the simulation results on various parameters. Finally, the result and future study are presented in section V.

II. Background and Related Works

The data collisions, retransmission, sensing, transmitting, and receiving consume the major part of IoT device energy [1]–[4]. The advanced technology such as an edge computing offloads computation from the cloud servers to the systems in the network edge, resulting in reduced latency [5]. Several authors proposed different approaches for cluster head selection based on distance and energy [6]–[8]. Some studies also take node degree [9], [10] and sink node location [11], in addition to distance and energy, into consideration while selecting cluster head. In research study [12], a fuzzy logic based approach is proposed. A distributed clustering technique [13] is proposed to overcome the energy hole problem. The cluster head selection was performed based on the distance, energy, sink node location, and node degree [13], [14]. The 5G and beyond networks can address several issues such as low data transmission rate, massive device connectivity, high delay, low QoS, low throughput, and low network capacity etc [15]–[22]. Moreover, the integration of D2D communication and IoT also have the ability to provide some of the requirements such as low delay, high network capacity, better spectral and energy efficiency of the 5G and beyond networks [15]–[22]. Several researchers proposed approaches for cluster head selection based on fuzzy logic [23], [24], dynamic reduction of information [25], optimization based clustering algorithm [26], dominant node [27]. The research [28] compares some of the most popular options in utilizing or adopting the new energy platforms, and a new set of IoT levels that evaluate IoT technology adoption. The LEACH [29]–[32] protocol partitions nodes into clusters, each headed by a singular node serving as cluster head. The primary duty of this designated node is to collect data from every other node within its cluster and transmit it to the sink node or base station. In LEACH-C [33], [34], the cluster head is selected based on the residual energy of nodes. Since energy is an important factor to consider while selecting nodes, HEED [35]–[37] algorithm spends more than conventional energy while stabilizing the election of cluster heads, but fundamentally, the algorithm is better than LEACH-C because of its less chance of selecting zero cluster heads in the beginning or towards the end of the network, unlike LEACH or LEACH-C that often give zero cluster heads during many rounds of election.

III. Proposed Work

A. Proposed Algorithm without Degree

Considering how LEACH-C and HEED take into consideration the remaining energy of nodes in two different forms, the authors are introducing another approach that takes energy and distance into consideration while selecting a cluster head in the system. Instead of dealing with probabilities, the authors are fixing the rate or probability of the cluster being selected and not leaving it on some random basis. On a practical level, the algorithms that the authors propose are made assuming that for each round in the network, there need to be cluster heads available and should not be zero in any case (unless of course when the system dies of energy). The cluster head selection algorithm decides whether a candidate node is suitable for cluster head selection, based on the average of distances to all nodes. The algorithm calculates the sum of distances between the candidate node and all other normal nodes and takes an average of this sum. Now for all nodes, the maximum energy, and minimum average distance node are then promoted from being a candidate node to the cluster head node for the network.

B. Proposed Algorithm With Degree

While experimenting with all the algorithms, the authors found there are some cluster heads that are being ignored by nodes because they aren't favored by nodes around them. This could happen if the selected node is either slightly further away from other normal nodes or if there is a better candidate for the normal nodes than this node. To determine these cluster heads, node degree is assigned to each cluster node. The algorithm takes 3% of operating nodes as a threshold for cluster node degree. Considering this approach, it is more accurate on a realistic level than the selection of cluster heads that sit ideal and waste aggregation and reception energy on no data collection. Also while experimenting, the authors tried to improve the speed of rounds by removing the compulsory re-election part in every round, as it was present in the proposed algorithm without Degree. This avoids going through the complex re-election process on every round and also improves the fluctuations in energy consumption in the network. Once the first round (takes place just like the proposed Algorithm without Degree) of election is done, normal nodes are assigned to each cluster head node and the degree of each cluster head node is calculated right at the time of assignment. For all subsequent rounds, all cluster heads are verified for their two parameters - (i) Cluster Head node degree $>$ 3% of operating nodes? (ii) Cluster Head remaining energy $>$ 20% of the initial energy of nodes? If any of the criteria fails for the cluster head, then it will be re-elected and substituted with another node in the network. This re-election check ensures there are no unnecessary re-elections taking place in subsequent rounds, considering each round valuable to energy preservation for the longevity of the network, which will be discussed later.

C. ABPL

Average link length is the average number of hops required to send a data packet from a cluster head node to the sink of the network. The backbone network is usually made up of cluster head nodes and the sink node, which are responsible for collecting information from other nodes. A smaller size of backbone network performs routing more efficiently, and it also reduces the control messages. The ABPL is a sum of hops between any pair of nodes in a backbone network (here, in this paper, one node will be the sink node and another will be a cluster head in a pair) divided by the number of all possible pairs of cluster heads. If a message travels in a backbone network of short ABPL (i.e. less hops) then such backbone network consumes less energy than if the same message travels in backbone network of long ABPL. It is also well known that if a message travels through more intermediate nodes to its destination then it has a high probability of the message getting lost or at least getting some propagation errors due to more intermediate nodes. Hence, a backbone network with short ABPL is more reliable than a backbone network with long ABPL. The ABPL [38] is calculated as -

$$ABPL = \frac{\textit{Total number of hops}}{\frac{\textit{Number of cluster heads}\times(\textit{Number of cluster heads}+1)}{2}} \quad (1)$$

D. LSP

LSP [38] is another quality factor for accessing a backbone network. However, it only considers the case of the longest paths in a network. This is the reason why the authors calculated ABPL as it provides a comprehensive idea of a network, as discussed in the section III-C. The LSP is the longest shortest path length between any pairs of nodes in a backbone network. A message may get transmission failure if it travels through more intermediate nodes (i.e. longest path). The LSP captures the worst case of ABPL. A backbone network with smaller LSP and ABPL is better.

IV. Simulation Results

A. Parameters for the Simulation

The simulation parameters are mentioned in table I. The configuration details for setting up the environment for simulation are - Software used for simulation: MATLAB R2022b (academic version), Debugging environment: Visual Studio Code Version: 1.77.3 (user setup), Operating System: Windows 11, 64-bit OS x64-based processor, RAM: 16.0 GB, HDD Memory: 1TB SSD, Processor: AMD Ryzen 7 5800H.

B. Network Distribution of all Nodes

The sink node is located at (x,y) = (990, 990) in a field size of 1000×1000. Nodes are distributed uniformly throughout the network because algorithms like HEED consume a lot

TABLE I: Parameters for the Simulation

Parameter	Value
x_max (length of the field)	1000 Meters
y_max (width of the field)	1000 Meters
$Sinkx$ (sink x coordinate)	990 Meters
$Sinky$ (sink y coordinate)	990 Meters
N (number of nodes)	100
E_o (initial energy of nodes)	0.1 Jules
E_elec (minimum energy/bit to operate a node)	$50 * 10^{-9}$ Joules/bit
E_tx (transmission energy)	Variable
E_rx (reception energy)	Variable
E_amp (amplification energy/bit)	$100 * 10^{-12}$ Joules/bit
EDA (data aggregation energy/bit)	$50 * 10^{-9}$ Joules/bit
K (bits per packet of data)	400
P (probability of CH selection)	0.1
Rad (radius of proximity)	200 Meters

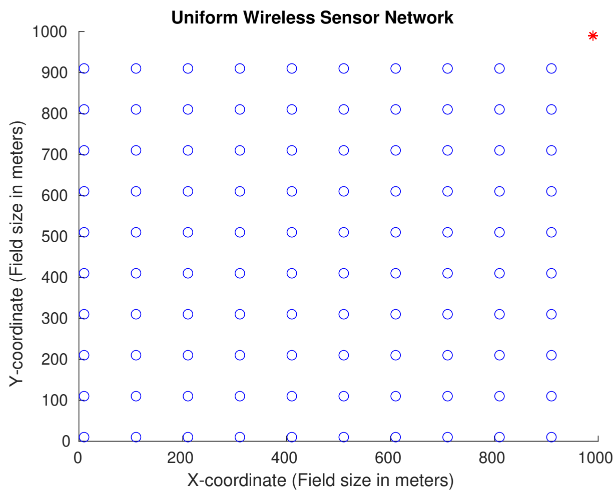

Fig. 1: Wireless Sensor Network with Uniform Distribution.

of energy in a randomly distributed network. In a random distribution, many nodes overlap each other, which is not ideal in the case of a real-life physical network. Nodes start from coordinate (x,y) = (0, 0) till (x, y) = (900, 900), distributed in steps of 10 meters of radius. All these aforementioned physical network specifications are shown in figure 1. The sink node and other nodes are shown in red color and black color respectively at aforesaid position in figure 1.

C. Transmission Energy per Round

A graph for transmission energy per transmission is drawn in figure 2. Transmission energy is the energy consumption of each round till the first node dies in the network for any algorithm. The graph is measured till the first dead node because once the first node dies, the number of nodes starts changing and then it would be complex to determine energy consumption based on rounds and also based on the number of nodes. LEACH and LEACH-C again can be seen taking almost the same amount of energy each round till the first node dies. HEED has the highest energy consumption rate which is in the nature of this algorithm as it takes multiple rounds to

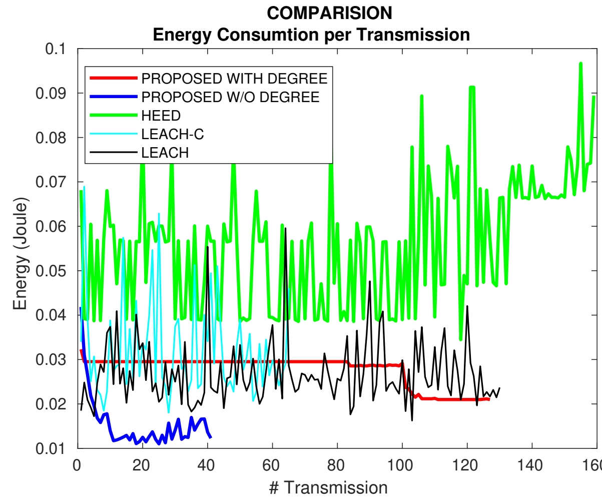

Fig. 2: Energy Consumption per Transmission.

stabilize and consumes a lot of energy doing so. Proposed Algorithm without Degree does the least energy consumption till the first node death which lies in its nature of selecting distance-biased nodes, as at the beginning of network rounds, energy bias is not present. Proposed Algorithm with Degree is very stabilized and the credit goes to it for not re-electing cluster head nodes at every round, unlike other algorithms that re-elect every round.

D. Alive/Operating Nodes per Round

A graph for operating nodes per round is represented in figure 3. This graph shows the number of nodes that have not failed or died during the operations of the network. For LEACH and LEACH-C, the nature is very similar due to the same probabilistic nature of algorithms, just that LEACH-C is better in terms of taking energy as a factor. HEED takes up a lot of energy in the start phase of its network, indicating that it's a highly energy-consuming algorithm compared to others. The Proposed Algorithm without Degree is very close to LEACH-C. The drastic fall in its graph is a consequence of a lot of cluster heads dying together in rounds that led to a sudden fall in the graph. The Proposed Algorithm with Degree outperforms all other algorithms because of its nature of not re-electing the cluster heads again and again at every round.

E. Data Packets sent to the Sink Node per Round

A graph for data packets sent to the sink node per round is shown in figure 4. This graph gives a deeper understanding of how the algorithms are running with the remaining number of nodes in the network. LEACH and LEACH-C show similar natures. Compared with other algorithms, their slope gets much flatter, showing that these algorithms are allowed to run with zero cluster nodes due to their absolute probabilistic nature. HEED with sharp peaks in the plot line, indicating a sudden decrease in the number of nodes (observed from the slope of the line) that is also summarized in the section IV-D. Proposed algorithms without Degree and with Degree have

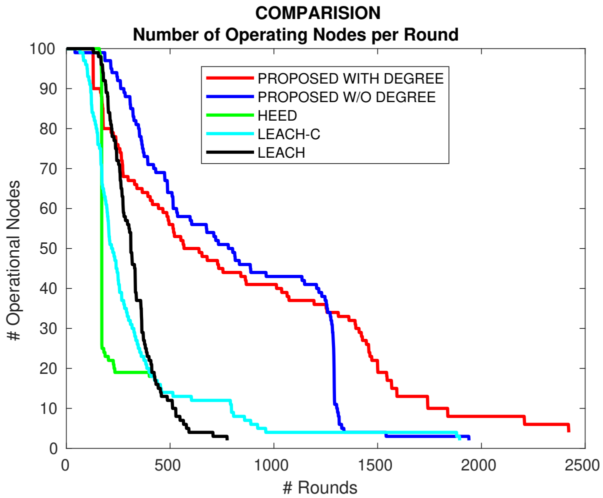

Fig. 3: Number of Alive/Operating Nodes per Round.

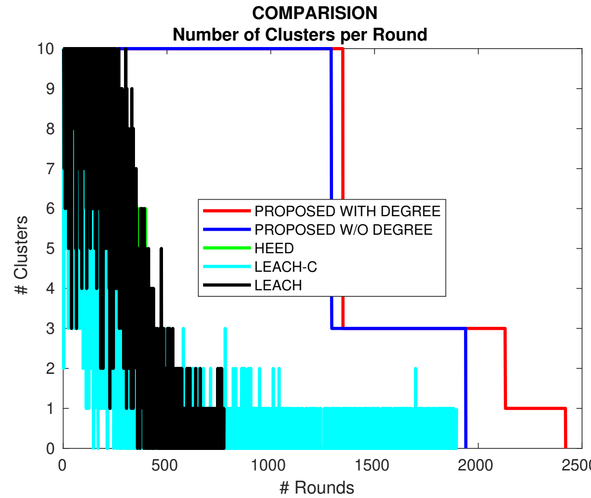

Fig. 5: Number of Clusters per Round.

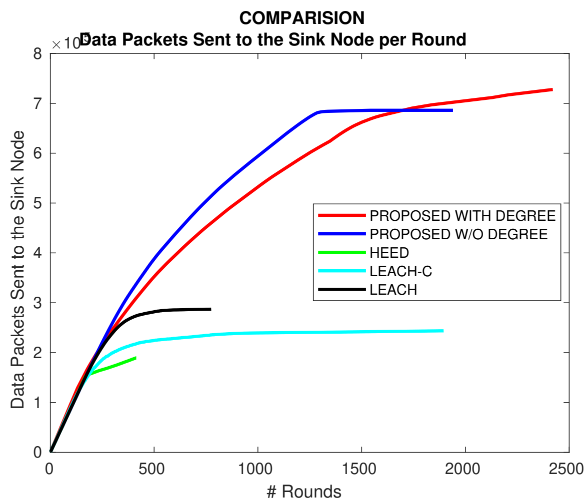

Fig. 4: Data Packets Sent to the Sink Node per Round

almost the same slope, just that the number of rounds where they stop, creates a difference.

F. Number of Clusters per Round

A graph for the number of clusters per round is represented in figure 5. The major difference can be observed in this graph as to what happens when the authors keep three algorithms run on probability and two algorithms that don't run on probability selection. LEACH and LEACH-C can be seen running for rounds without cluster heads, which is not truthful in real life, because without cluster heads those rounds are wasted. HEED can be seen as having almost the same probabilistic nature, however, due to its nature of energy consumption, it runs lesser rounds. The Proposed Algorithm without Degree has a sudden fall in the number of clusters in its algorithm which can be explained due to its nature of compulsory cluster head selection and nodes dying together in the network. Proposed Algorithm with Degree is very similar to without Degree, however, the difference is a factor of selecting cluster head nodes with Degree and also no re-election at every round.

G. Remaining Energy per Round

A graph for remaining energy per round is drawn in fig 6. LEACH and LEACH-C again show that the nature of energy distribution as well as consumption is similar. HEED has a very sharp depletion that proves the points of high energy consumption of this algorithm during the start of the algorithm, also summarized through sections IV-C, IV-D, and IV-E. Proposed Algorithm without Degree has a lot of remaining energy in its system. This is because the node selection is very uniform and energy depletion is uniform as well. This leads to all nodes going below 20% of the threshold value together, leading to the algorithm to stop with most nodes at 20% of the remaining energy. Proposed Algorithm with Degree uses energy uniformly and has cluster heads take the first hit by getting depleted, then subsequent cluster heads take the hit. This keeps on happening, with which most normal nodes keep depleting energy too. This kind of energy depletion is suitable where once cluster heads are selected, the network stabilizes, and there's no need for re-election unless and until necessary in the system.

H. Average Backbone Path Length (ABPL) per Rounds

The ABPL values per round are mentioned by a graph in figure 7. As discussed before ABPL, the comparison fits well when the authors compare proposed Algorithm without Degree and with Degree because in the case of LEACH and LEACH-C, their cluster head selection goes zero, which means in those rounds they can have ABPL as zero. The flat lines at the end of proposed Algorithm with Degree are because of two reasons- (i) Very few nodes remain in the network in this stage, and (ii) Re-elections have almost stopped since there aren't many nodes to choose from, in order to re-elect a cluster head.

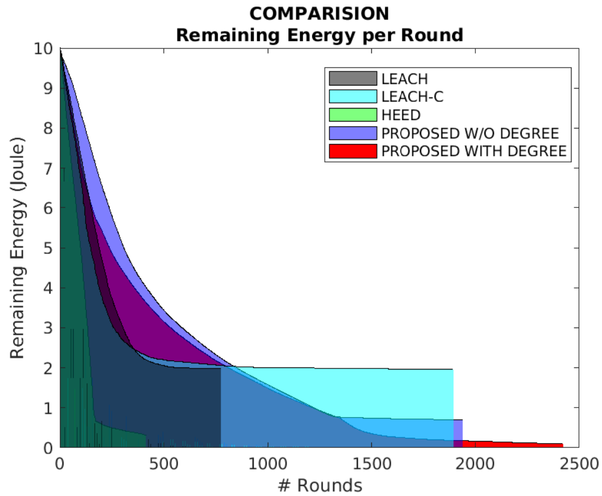

Fig. 6: Remaining Energy per Round.

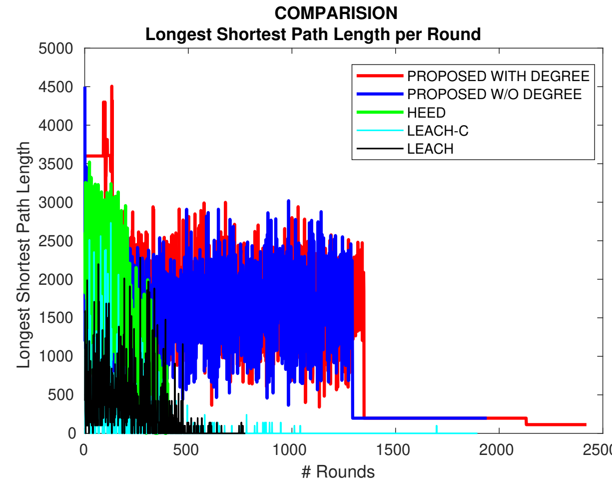

Fig. 8: Longest Shortest Path per Round.

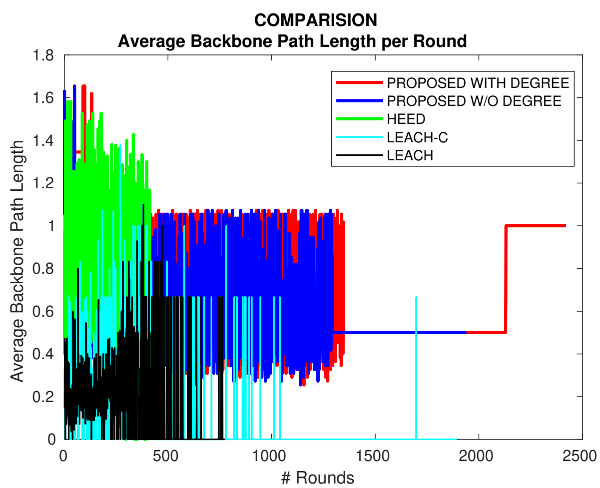

Fig. 7: Average Backbone Path Length per Round.

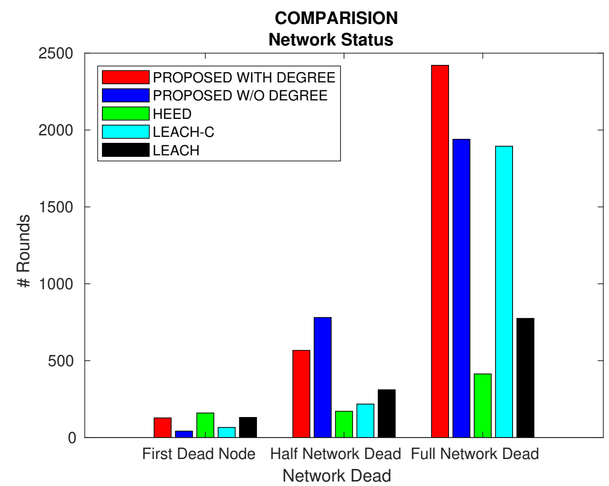

Fig. 9: Network Status

I. Longest Shortest Path (LSP) per Round

The LSP per round is shown by a graph in figure 8. Just like ABPL, LSP gives a similar graph at a broader level because the calculation of both these parameters comes from finding the best path for each Cluster Head node. The flat line at the end of the proposed Algorithm with Degree has the same reason as discussed in the section III-C.

J. Network Status vs Number of Rounds

A graph for network status is drawn in figure 9. This graph can be synonymously used with other graphs to analyze the lifetime of the network and also crosscheck with other results of this simulation. This graph shows that when the first node, half network, and full network died.

V. Conclusions

Using these simulation results from MATLAB and after analysis of all the graphs of the algorithms, the authors can conclude that the proposed Algorithm with Degree can outperform other algorithms at good levels. For the practical applications of LEACH variants, the proposed Algorithm with Degree should work most realistically in real environments while electing cluster heads and maintaining the system in a stabilized environment. However, since the values of ABPL and LSP are being overtaken by LEACH and LEACH-C due to the selection of zero cluster heads problem. Hence, this could be an area of improvement for the proposed algorithms. But these conclusions can only be deduced from testing these algorithms on a live network. The values might feel good at the current stage, but only on a practical level can be understood how the network would behave when no Cluster Head node is selected in the network. To summarize, the proposed Algorithm with Degree has four important additions to the LEACH variant algorithms - (a) Using maximum energy and minimum distance into consideration while selecting the cluster head nodes in the network, (b) No re-election in all rounds of execution to avoid destabilizing the network, (c) Use of node degree of cluster heads for re-election to avoid having cluster heads that connect to no nodes or below threshold nodes in the network, and (d) Removing the probabilistic nature of LEACH from the proposed algorithm to ensure compulsory Cluster Head selection.

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