An Energy-Oriented Node Characteristics-Aware Routing Algorithm for Wireless LAN

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***Abstract*—A growing number of different technology-supported wireless networks are being deployed everywhere including many public areas, people of different ages are using increasingly complex battery-powered devices and various rich media networked applications have an exponentially growing popularity. In this context of high diversity and heterogeneity of devices, networks and applications, energy is a limited and highly valuable resource on which high quality service provisioning to users is highly dependent. This paper proposes an Energy-oriented Node Characteristics-Aware Routing Algorithm (ENCARA) which considers energy-related node characteristics in the routing process. ENCARA differentiates nodes by their characteristics and will conserve energy of those nodes with critical energy constraints, while maintaining the overall routing performance at high levels.**

***Index Terms*—Energy-aware routing, Wireless LAN**

I. Introduction

IN ad hoc and mesh wireless networks, the energy-related constraints may not be identical in all the nodes. For example, hardware-wise, some nodes may be powered by batteries with limited lifetime, while others are powered by mains. Besides, unlike wireless sensor networks, the energy consumption is not mostly affected by the network traffic, but by other factors, such as features of the hardware (LCD screen or CPU specifications). Software-wise, different software applications (e.g. online gaming, multimedia streaming, web browsing) affect energy depletion differently and significantly. In a context where maintaining connectivity is paramount, it is important to conserve energy, especially in those devices with strict energy constraints, so that they could continue to provide service and make the network survive longer. In order to address this issue, there is a need for an energy-aware routing algorithm which considers the specific features of the intermediate nodes, both in terms of hardware and software, when performing routing.

This paper proposes an *Energy-Oriented Node Characteristics-Aware Routing Algorithm (ENCARA)* for data exchange in wireless networks that considers along network performance and energy consumption for data transfer also *the energy-oriented node characteristics of the intermediate nodes (hardware and software)*. It involves nodes exchanging energy consumption and performance information among them, while also indicating node features, information required in order for routing decisions to be made in such a way that performance and energy efficiency is balanced.

The paper presents simulation tests which employ "battery-powered" and "mains-connected" nodes which perform "multimedia streaming" or "web browsing" in an ad-hoc wireless LAN. Test results show how ENCARA achieves up to 56% better results in terms of energy efficiency than when AODV [1] is used, while reaching 91.7% of the throughput of the AODV in a static scenario. In addition, ENCARA performs even better in a mobility-oriented scenario with 150% higher remaining energy level and lower delay in comparison with the AODV case.

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II. Related Works

A. Power-related Metrics-based Routing

Research has already been performed in the energy-aware routing area with promising results. An early attempt is the Minimum Total Transmission Power Routing [2], which selects the route with the least energy cost along the path as the optimal choice for data transmission. Battery-aware routing protocols are enhancements of this early approach and include the Minimum Battery Cost Routing (MBCR) [3], Min-Max Battery Cost Routing (MMBCR) [3, 4] and Conditional Min-Max Battery Cost Routing [4], a hybrid solution which mixes MBCR and MMBCR. Instead of looking into the total energy consumption along the route, these solutions take into account total remaining battery capacity of the nodes.

When performs routing, the Flow Augmentation Routing (FAR) [5] considers three factors: the cost for a single transmission along the path, the initial energy of the node and the residual energy at the transmitting node. The Online Max-Min Routing Protocol (OMM) [6] takes into account the residual energy after transmission instead of the current residual energy to avoid overuse certain nodes.

B. TDMA Solutions

The authors of [7] propose an energy-aware routing algorithm for ad-hoc and sensor networks employing a TDMA communication scheme. In this schema, every node can only

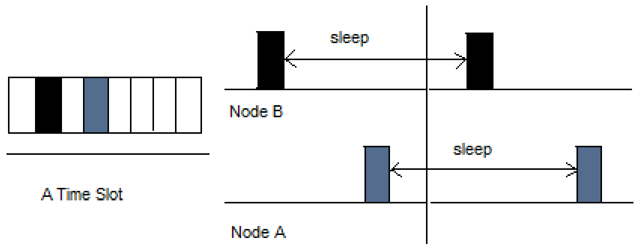

Fig. 1. TDMA solution allows nodes to sleep for a certain period in order to conserve energy

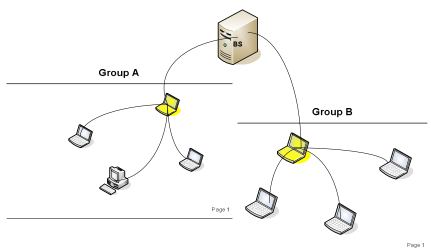

Fig. 2. The connectivity between nodes in LEACH

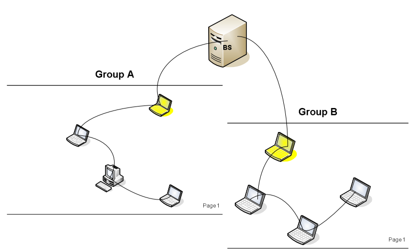

Fig. 3. The connectivity between nodes in PEGASIS

communicate with two neighbors, and the protocol allows each pair of neighbor nodes to negotiate a time slot for bidirectional communication in an initial phase. Then each pair of nodes wakes up according to a pre-negotiated time schedule only and rest for the remainder of the time. In this manner, nodes can save energy by sleeping, and the amount of saved energy depends on the duration of rest time. Note the routing protocol carefully selects routes that fill in as many non sleeping hops in a time slot as possible. Otherwise, the performance decreases too much.

C. Hierarchical Routing

Hierarchical routing is another solution to improve energy efficiency from the routing point of view. Hierarchical routing requires electing a special node in order to route all communication within certain area through it. The special node is elected either by making use of a certain criteria or in turn. Most nodes (regular nodes) will not communicate directly with the base station; instead they will communicate with the special node which is nearer to them in order to preserve energy. Solutions in this category include the Low Energy Adaptive Clustering Hierarchy (LEACH) [8, 9] and Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [10, 11]. LEACH, illustrated in Fig. 2, is a cluster based solution, where nodes are divided into clusters with a node randomly selected as cluster head for communication with the base station, while other nodes communicate only with the cluster head PEGASIS, seen in Fig. 3, is a chain-cluster based approach, which is an enhancement of LEACH and allows nodes to communicate only with neighbors in order to reduce each node's energy consumption even further. The Consumed Energy Type Aware Routing (CETAR) [12] differentiates nodes by their major role (receiver or sender) played in the wireless network.

D. Cross Layer Solutions

The Minimum Energy Routing protocol (MER) [13] combines the Dynamic Source Routing (DSR) [14] and the IEEE 802.11 MAC layer protocol [15] with optional configurations to conserve energy. SPAN [16] also works between MAC and routing layer which allows it to make use of MAC layer's energy conserving mechanisms in conjunction with network layer's energy saving mechanism.

E. Location Aware Solutions

The Geographic Adaptive Fidelity Protocol (GAF) [17] makes use of location information gathered from GPS to form "virtual grids" and selects master node for nodes in one grip to perform routing. The Power Aware Localized Routing Protocol (PLR) [18] is a localized routing protocol assuming nodes to know only location information of neighbors and destination. In this manner, source nodes need only to find the best route to next stop rather than optimal route to the destination.

Compared with the above solutions, ENCARA introduces the "node characteristics" as a new manner to differentiate nodes in a wireless network environment, and based on that enable to conserve more energy of some nodes such as for example all "battery-powered, performing multimedia streaming" nodes.

Additionally ENCARA is based on a flexible cost function which is open to further improvements by using a finer granularity with regards to the hardware or software issues. ENCARA can also be applied in conjunction with some of the other solutions, such as for example LEACH [8, 9].

III. Energy-Oriented Node Characteristics-Aware Routing Algorithm (ENCARA)

A. Introduction

ENCARA makes use of the on-demand feature of AODV [1], and enhances the energy efficiency and the performance in static and mobile scenarios by employing a new cost metric, a suboptimal route avoidance scheme and a periodically request-based update scheme. By doing this, ENCARA takes into account delivery performance, energy consumption for data transfer and the characteristics of the intermediate nodes (hardware, e.g. power source, hardware specifications, etc., and software applications).

B. Principle

As any routing protocol, ENCARA is a network layer protocol. It chooses an optimal route based on a cost function from possible alternative solutions as shown in Fig. 4. The figure illustrate a situation when different energy constraints are considered: laptops are powered by batteries and run multimedia streaming applications; mains-connected desktops are equipped with high spec hardware and run online gaming

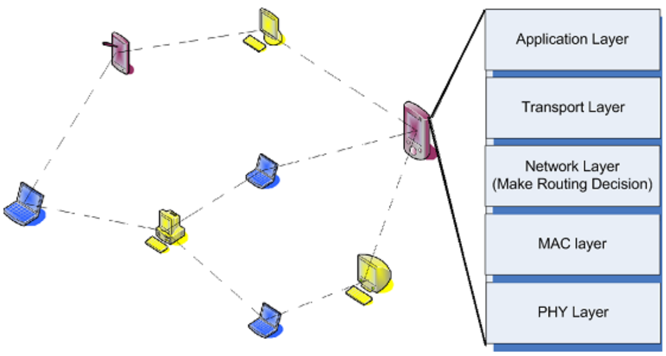

Fig. 4. Wireless network comprised of different end systems with various features and it gives several routes from the source to the destination

applications; smart phones are battery-charged low spec devices and run web browsing applications.

Under such circumstances, ENCARA will carefully select routes by primarily making use of desktops to act as routers and not encouraging laptops to forward data packets to other node, therefore saving energy of the battery powered nodes. Additionally, among the battery powered nodes, laptops running multimedia streaming applications have higher energy demands and will also be spared when performing routing. Besides, the nodes with lower remaining energy levels are also protected, in order to give users more time to save changes before the devices run out of power.

The routing mechanism of ENCARA is illustrated in Fig. 5 and Fig. 6. Each node will evaluate the cost of each route and will keep record of the optimal route to the destination, according to which, further data packets will be sent to the destination correctly.

C. Major Contribution

Although ENCARA makes use of the on-demand feature of AODV [1], it has three major novel contributions in order to increase energy efficiency and better support mobility.

1) Energy-Oriented Node Characteristics-Aware Metric

As already mentioned, the features of the devices can vary significantly. For instance, gaming and streaming applications have increased energy requirements in comparison with web browsing; often high-spec hardware consumes energy at a higher rate than low-spec hardware; devices with less battery capacity need to be protected better than those with full battery levels, or mains powered. This paper proposes a new metric which grades software and hardware node characteristics.

2) Suboptimal Route Avoidance Scheme

AODV uses suboptimal routes even in low mobility situations. AODV selects an optimal route among several candidates at first and refuses to update to a more efficient route unless links break or the topology changes. However, ENCARA is open to new incoming notifications as long as a more optimal route is provided in order to achieve better performance.

3) Periodical Request-Based Update Scheme

This solution allows the data source periodically send a new route request to the destination to acquire the optimal routes in accordance to new energy distribution in the whole network.

D. Route Cost Computation

$$C_{node} = W_1 \cdot G_1 + W_2 \cdot G_2 + \ldots + W_n \cdot G_n \quad (1)$$

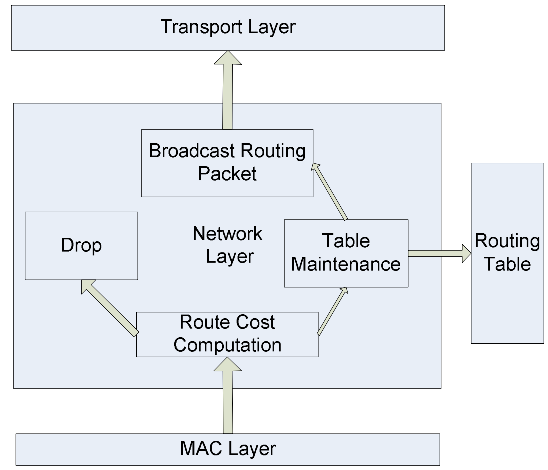

Fig. 5. Processing receiving routing packets

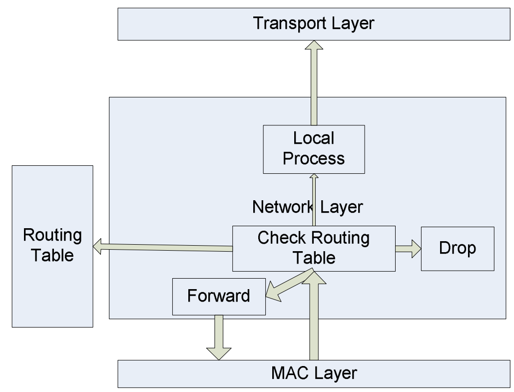

Fig. 6. Processing receiving data packets

The open cost function proposed in (1) it is employed to evaluate the benefit of having the traffic passing through a particular node. The different components G_i in the equation represent grades which evaluate the benefits of different energy–related node aspects. Different weights W_i are associated with these grades in order to strengthen the contribution of one or another of these components to the overall cost.

$$C_{node} = G_{elevel} = \frac{1}{e^{E_{current}/E_{initial}}} \quad (2)$$

A simplified version of ENCARA denoted ENCARA_S will be using equation (2) as the node cost function, and employ the suboptimal route avoidance and periodical update request mechanisms. In (2), $E_{initial}$ and $E_{current}$ are the initial and current energy levels of the node and are expressed in J. ENCARA_S evaluates the remaining energy of each node only and selects the route which includes the nodes with the highest remaining energy levels.

$$\begin{aligned} C_{node} &= W_{nchar} \cdot G_{nchar} + W_{elevel} \cdot G_{elevel} \\ &= W_{nchar} \cdot (G_{app} + G_{power})/2 + \frac{W_{elevel}}{e^{E_{current}/E_{initial}}} \end{aligned} \quad (3)$$

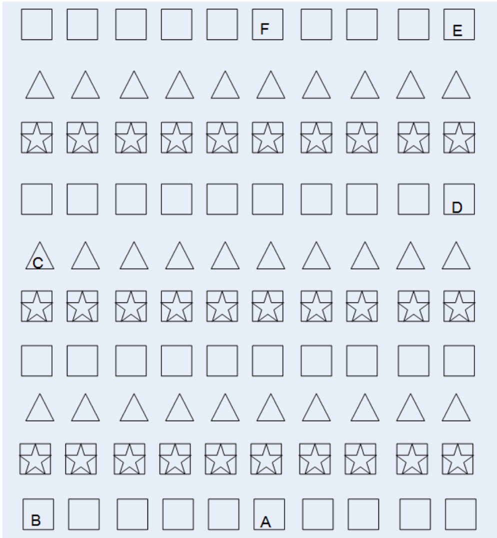

Fig. 7. The distribution of nodes in the simulation

The full version of ENCARA considers the node cost function expressed by equation (3). In (3), the cost of route passing through the node, expressed as a normalized value in the [0, 1] interval, has two components: G_{nchar} - grade of energy-based node characteristics and G_{elevel} - grade of remaining energy level. G_{app} and G_{power} are grades which describe the application and power source, respectively.

G_{nchar} metric covers both hardware and software features. Currently, the hardware component only refers to the type of power source: battery -powered or mains-connected. G_{elevel} is an exponential distributed function, which will increase faster than linear function when the remaining energy is closer to zero. This is to reflect the fact that lower energy capacity is more critical and requires stronger and faster actions to be taken..

In the above equation, the variation of weight values affects the contributions of the two factors and consequently influences the results in terms of performance and energy savings. It would not be fair to over address the energy concern at the cost of severe performance compromise. Additionally, a potential low energy consuming route with fairly big delay or/and low throughput is not an option; a constant use of one single optimal route would deplete the energy of the nodes along that "optimal route" which could lead to network partition. Thus weight values need to be carefully selected and fully tested.

$$C_{route} = \sum_{i}^{n} C^{i}_{node} \quad (4)$$
$$= \sum_{i}^{n} \left(W_{nchar} \cdot (G^{i}_{app} + G^{i}_{power})/2 + \frac{W_{elevel}}{e^{E^{i}_{current}/E^{i}_{initial}}} \right)$$

Finally, the overall cost of the route is given by the sum of the costs along the path, as illustrated in equation (4). Among the multiple alternative routes from source to destination, the one with least cost is selected and stored in the routing tables.

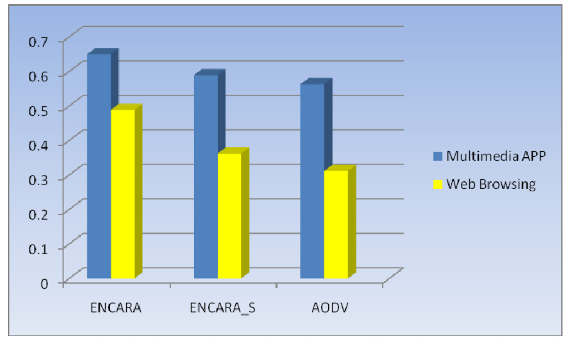

Fig. 8. Energy levels for nodes performing multimedia streaming and web browsing respectively (static case)

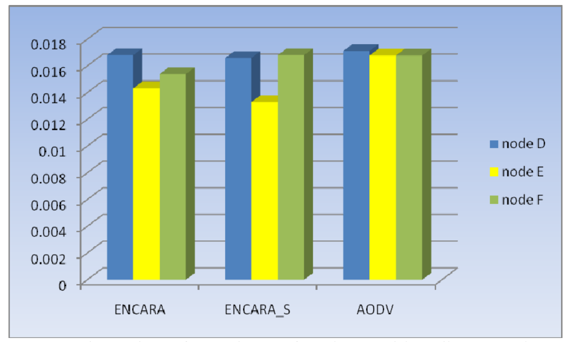

Fig. 9. Average throughput for nodes performing multimedia streaming and web browsing respectively (static case)

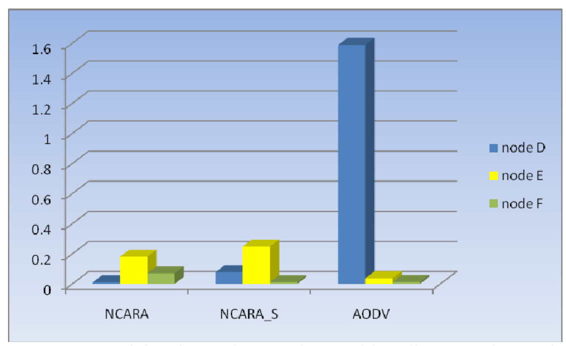

Fig. 10. Average delay for nodes running multimedia streaming and web browsing, respectively (static case)

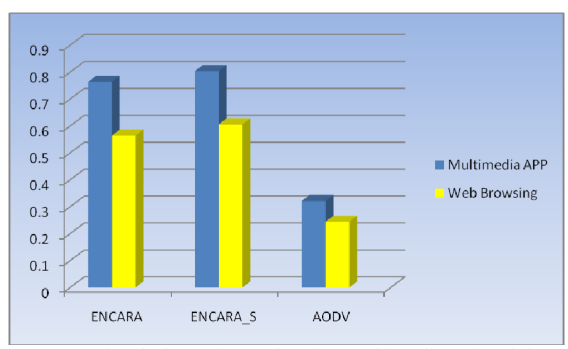

Fig. 11. Energy levels for nodes performing multimedia and web browsing respectively (random mobility case)

IV. ENCARA Testing

ENCARA is modeled and tested using Network Simulator v. 2.34 (NS 2) [19] in a 115 meter * 115 meter grid topology of an

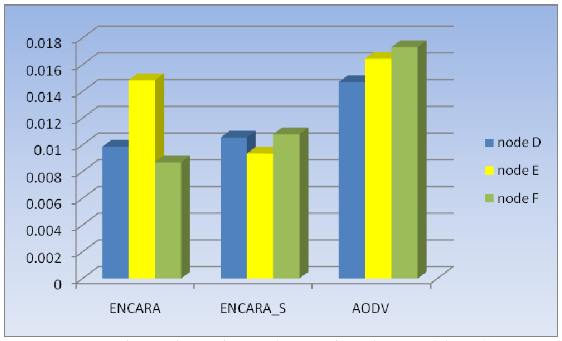

Fig. 12. Average throughput for nodes performing multimedia streaming and web browsing respectively (random mobility case)

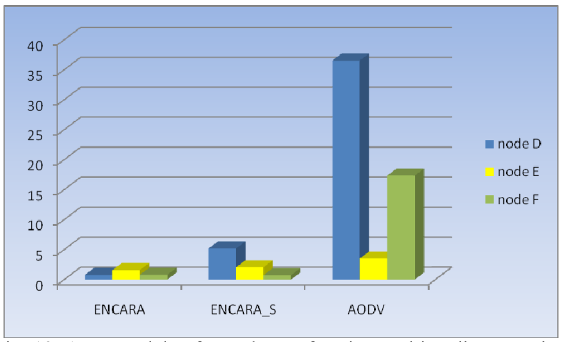

Fig. 13. Average delay for nodes performing multimedia streaming and web browsing respectively (random mobility case)

ad-hoc WLAN comprised of 100 nodes situated at 10 meters distance between each other as illustrated in Fig. 7. 30 nodes (represented as triangles in the figure) are mains-connected and others are battery powered. 40 of the battery-charged nodes (squares) are set to run multimedia streaming applications and the rest of the battery powered nodes (represented as stars) are defined as performing web browsing. The widely deployed IEEE 802.11b [15] is used as the MAC protocol. Tests involve a static and a random mobile scenario.

In terms of the energy constraint, the total energy capacity for each node is set to 2 J, whereas the transmitting power and receiving power are set to 0.035 J and 0.031 J, respectively. The total time for each test is 400 seconds. The range of each node is defined as 30 meters.

Constant bit rate data traffic of 1Mbps is used in all tests. Three flows of constant bit rate traffic are defined (node A to node D, node B to node E and node C to node F in Fig. 4).

The proposed solution ENCARA is tested against ENCARA_S and AODV [1]. The grades from equations (5) and (6) are used in the tests:

$$G_{nchar} = \begin{cases} 0.1 \text{ (web browsing on battery powered nodes)} \\ 0.6 \text{ (rich media streaming on battery powered nodes)} \\ 0.0 \text{ (any applicatio n on mains - connected nodes)} \end{cases} \quad (5)$$

$$G_{elevel} = \begin{cases} 0.2 \text{ (mains - connected nodes)} \\ 0.4 \text{ (battery powered nodes)} \end{cases} \quad (6)$$

W_{nchar} and W_{elevel} are set to 0.4 and 0.6, respectively. However, the weights can be set differently in different situations.

TABLE I
RESULTS FROM STATIC SIMULATIONS

	ENCARA	ENCARA_S	AODV	ENCARA /AODV
remaining energy for streaming node (J)	0.650	0.589	0.563	115.4%
remaining energy for web browsing node (J)	0.489	0.362	0.311	156.9%
average throughput (Mbps)	0.016	0.016	0.017	91.7%
average delay (sec)	0.087	0.112	0.546	15.9%

TABLE II
RESULTS FROM MOBILITY-BASED SIMULATIONS

	ENCARA	ENCARA_S	AODV	ENCARA /AODV
remaining energy for streaming node (J)	0.764	0.804	0.321	234.7%
remaining energy for web browsing node (J)	0.564	0.606	0.244	231.0%
average throughput (Mbps)	0.011	0.010	0.016	68.9%
average delay (sec)	1.042	2.645	19.110	5.4%

Table I presents the results of the simulation in which all the nodes were static. According to the results, ENCARA saved with 15.4% more energy than AODV [1] for devices running multimedia applications, and with 56.9% more energy for devices doing web browsing. On average the proposed solution ENCARA achieved 91.7% of the throughput of the AODV and 15.9% of the average delay achieved by AODV.

Table II presents the results of the mobility-based simulations. It can be clearly seen how ENCARA outperformed AODV in energy efficiency once more, as it saved up to 134.7% more energy in this mobile scenario. Since ENCARA employed the suboptimal route avoidance algorithm and periodical update request mechanism, it has superior results when dealing with mobility. This can be further demonstrated by the fact that it experiences only around 5% of the average delay of the AODV. However, the throughput given by ENCARA was only 68.9% of that of AODV.

V. Conclusion

This paper introduces a novel *Energy-Oriented Node Characteristics-Aware Routing Algorithm (ENCARA)* which offers advantage over AODV in terms of energy efficiency and mobility without much performance compromises. In a static scenario, ENCARA saves 56.9% more energy than AODV with achieving 91.7% of the throughput and 15.9% lower delays. For the random mobile nodes case, ENCARA saves up to 134.7% more energy, while experiencing with 5.4% of the delay, and 68.9% of the throughput of the AODV.

Future work includes a refined definition of the energy-oriented node characteristics-aware routing algorithm and its cost function with regard to the hardware and software contributions with increased granularity.

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