Performance of WLAN RSS-based SON for LTE/WLAN access network selection

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Abstract — **Mobile Network Operators (MNOs) are integrating carrier-grade Wireless Local Area Network (WLAN) to cellular networks to improve network performance and user experience. Access network selection (ANS) between cellular and WLAN plays a key role in the integration. Given the complexity of heterogeneous networks characterized by multiple network layer deployments and inhomogeneous traffic distribution, the ANS has to automatically adapt to dynamic network conditions. In this article, we present and evaluate a Self-Organizing Network (SON) algorithm for tuning the ANS between the Long Term Evolution (LTE) and WLAN systems. The proposed SON algorithm adopts a WLAN received signal strength (RSS) threshold to control the access selection. The RSS threshold is updated by the SON algorithm based on periodically monitored load in the LTE and WLAN systems. The SON algorithm is evaluated by simulations in realistic heterogeneous network scenarios and proved effective in improving user experience.**

Keywords—LTE, self-organizing network, WLAN, network selection, network optimization.

I. INTRODUCTION

As the amount of data traffic has grown explosively during the past few years [1] [2] and the amount of available licensed spectrum is limited, Mobile Network Operators (MNOs) are looking into the offloading of cellular network data to Wireless Local Area Networks (WLANs) as most mobile devices support both radio accesses. Nowadays the selection between the cellular system and WLAN is however still manually controlled by the users who will typically use WLAN when available. More intelligent access network selection (ANS) between the two systems is a key technology to improve service quality and system efficiency. Given the complexity of emerging heterogeneous networks characterized by multiple network layer deployments and inhomogeneous traffic distribution, the ANS has to be adaptive to dynamic network conditions.

A number of previous literature studies modelled the ANS as an optimization problem with a multi-dimensional utility function that takes various parameters such as load, throughput, QoS, resource utilisation costs and battery lifetime into account [4], [5]. These solutions rely on a large amount of information exchange between networks/devices and standardization supports are required for the cross-system communication.

In 3rd Generation Partnership Project (3GPP), an Access Network Discovery and Selection Function (ANDSF) [6] is specified to assists terminals in network discovery and selection with semi-static policies. Since the current ANDSF policies are not adaptive to dynamic radio environments, a

3GPP work item titled "WLAN/3GPP Radio Interworking" [7] has been established to have assistance from radio access networks (RANs) for the ANS mechanism. In the WLAN standardization community, Hotspot 2.0 specifications by the Wi-Fi Alliance aim at providing information, e.g. WLAN radio load and backhaul load [8], and policies to terminals for network discovery and selection.

Taking the current status in standardization into consideration, Self-Organising Networks (SON) is a promising solution for the ANS with relatively low complexity and potentially high efficiency [3]. SON algorithms are close-loop functions that continuously monitor network performance and autonomously update control parameters to achieve optimization targets. In this paper, a SON algorithm for the ANS between the Long Term Evolution (LTE) and WLAN systems is proposed and evaluated. The SON algorithm targets at improving user experience with limited complexity in dynamic heterogeneous network environments.

The remaining of the paper is organised as follows. A SON algorithm for the ANS is proposed in Section II. System modelling and scenario for performance evaluation is described in Section III. Following a controllability study in Section IV, the SON algorithm is evaluated in Section V. The paper is finalized with conclusions and recommendations in Section VI.

II. WLAN RSS-BASED SON ALGORITHM FOR ACCESS SELECTION

The SON algorithm studied in this paper essentially balances the load between the LTE and WLAN systems to improve overall user experience. A flowchart of the algorithm is illustrated in Figure 1, and the mechanism controlling the ANS is explained in details in this section.

A. Control parameter

A WLAN Received Signal Strength (RSS) threshold (*RSS_Thr*) is adopted as a control parameter to determine the ANS. The control mechanism is defined by a simple rule based on the terminal measured RSS and the *RSS_Thr*,

> IF $RSS > RSS\_Thr$
> THEN UE served on WLAN
> ELSE UE served on LTE

The rule is applied when a user session is initiated. Terminals located in a close proximity to a WLAN access point (AP), i.e. RSS>*RSS_Thr*, will be served by the WLAN network. The *RSS_Thr* is assumed to be AP specific and effectively determines the size of the AP serving area, i.e. a

larger *RSS_Thr* corresponds to a smaller serving area and vice versa.

Two RSS measurements, Received Signal Strength Indicator (RSSI) and Received Channel Power Indicator (RCPI), are defined in the 802.11n standard [9]. As specified in the standard, the RCPI shall equal the received Radio Frequency (RF) power within an accuracy of ±5 dB (95% confidence interval). Given the accuracy requirement, the RCPI is under consideration to be standardized as an access selection control parameter in 3GPP [7]. In this paper, instead of the standardized indicators that are indexes mapped from the RSS values the RSS in dBm is used in the study without losing generality.

An initial value (*RSS_Thr_Initial*) and upper/lower bounds (*RSS_Thr_Max/RSS_Thr_Min*) of RSS_Thr are configured. And an update step size (*RSS_Thr_Step*) is specified to control the magnitude of adjustment in each step of SON iteration.

B. Monitoring KPI

The SON algorithm obtains performance status feedback by monitoring one or more Key Performance Indicators (KPIs). In this study, LTE cell load and WLAN AP load is adopted as the monitoring KPIs due to their high correlation to user throughput and relatively low complexity to monitor.

The LTE cell load (L_L) is measured by the downlink (DL) Physical Resource Block (PRB) utilization percentage. The WLAN load (L_W) is represented by the percentage of average channel busy time of a WLAN AP and is based on the Basic Service Set (BSS) load element information certified by the Hotspot 2.0 specification [8]. The WLAN channel is considered as busy if there is at least one active connection associated to the AP and the AP or a terminal is transmitting.

The load is averaged over a measurement period represented by p_L and p_W in LTE and WLAN, respectively. The measured load is further filtered as

$$L(n) = (1-\alpha) * L(n-1) + \alpha * L_{measured}(n) \qquad (1)$$

where L(n) is the filtered load at the nth measurement period, α is the filtering factor and $L_{measured}(n)$ represents the nth measured load. The same formula applies to both LTE and WLAN systems.

C. Offloading and Onloading

Due to the different load definition, the two KPIs shall not be compared directly against each other. Instead, separate load thresholds are defined for each system. When both systems are highly congested, i.e. the filtered loads as specified in equation (1) are larger than 95%, no action will be taken. When the load is larger than a high load threshold (*Thr_High_LTE / Thr_High_WLAN*), an offloading procedure is triggered to steer more users to the other network by adjusting the *RSS_Thr* accordingly. If no system is highly loaded and the load of a network is below a low load threshold (*Thr_Low_LTE / Thr_Low_WLAN*), an onloading procedure is started. In both procedures, the LTE load is checked before the WLAN load which gives the LTE system a higher priority. The adjustment of the *RSS_Thr* is regulated to a range between the *RSS_Thr_Min* and *RSS_Thr_Max*.
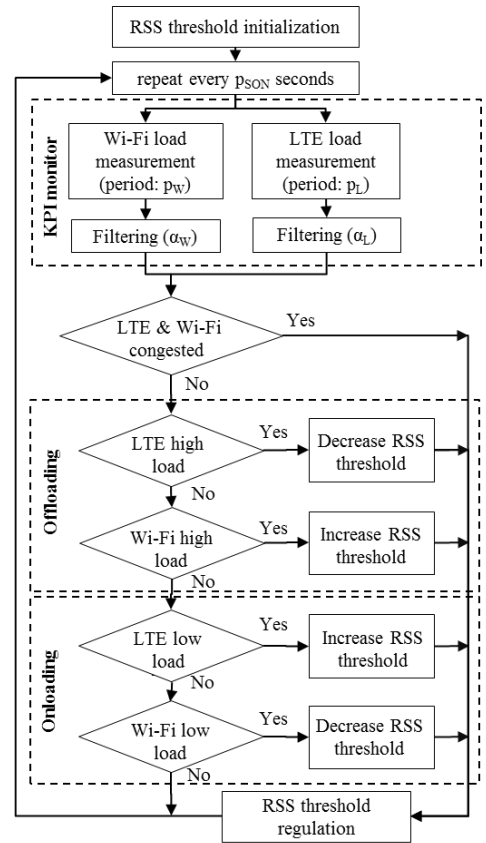

Figure 1: Flow chart of the WLAN RSS-based SON algorithm for LTE/WLAN access network selection.

Operator policies may be realized by setting the thresholds. For example, a policy of serving the terminals with the LTE network when network load is low may be realized by setting a high *Thr_Low_LTE* to onload the LTE system until the LTE load reach *Thr_Low_LTE*.

D. Iteration

The SON algorithm is iterative and performs the KPI evaluation and *RSS_Thr* adjustment periodically every P_{SON} seconds.

E. Implementation Aspects

A SON solution for ANS may be either controlled by a central entity, e.g. an ANDSF server, or deployed in a distributed manner and executed autonomously in radio access nodes. The RSS-based SON algorithm is primarily a distributed solution because it may be difficult for the central controller to execute an algorithm which updates parameters every few seconds.

To implement the access selection rule, one solution is to send the *RSS_Thr* to terminals via either broadcasting or dedicated signalling channels which is under discussion in 3GPP. The rule is then executed in the terminals. An alternative approach is a network based solution where the uplink RSS is monitored at the network node and the node controls the access selection. This approach does not require standardization support but needs the network node to be capable of steering the terminals to the selected RAT.

Since the algorithm takes the load from both LTE and WLAN as input, information exchange between the two systems is required, which may either rely on terminals as relays [10] or on proprietary interfaces. Standardization of such an interface is being discussed in 3GPP.

III. System Modelling and Evaluation Scenario

The proposed SON algorithm was evaluated by system level simulations in realistic heterogeneous network scenarios.

A. System Modelling

The LTE system modelling is fully compliant with the 3GPP Release 8 specifications. The system has 20 MHz system bandwidth at the 1.8 GHz frequency band. The macro and micro layers operate at the same frequency band with transmission power of 46 dBm and 33 dBm, respectively. LTE cell selection is Reference Signal Received Power (RSRP) based with a 6 dB offset applied to all the micros to extend micro cell ranges. The WLAN system modelling follows the 802.11n PHY/MAC layer specifications [9] with 20 MHz system bandwidth and 15 channels at 5 GHz. The transmission power is 20 dBm. The antenna configuration in both systems is 2x2 Multiple Input Multiple Output (MIMO). In a system capacity comparison, while the LTE has dedicated 20 MHz bandwidth for both DL and uplink (UL) traffic, the WLAN has more radio channels hence less inter-AP interference.

B. Evaluation Scenario

The evaluation scenario is characterized by an outdoor hot zone located in a shopping street area in the city centre of Hannover which is covered by three network layers as shown in Figure 2. The deployment includes 28 co-sited outdoor LTE micros and WLAN APs in addition to 5 LTE macro sites. Omni-directional antennas of the co-sited micro/APs are installed on lampposts at 5 m height.

User traffic is generated by the User Datagram Protocol (UDP) with fixed size file downloading and uploading from stationary users. A high load condition is configured by setting a Poisson arrival rate of users in the area to 12 arrivals per second. The downloading and uploading file sizes are 5 MB and 0.8 MB, respectively.

IV. Performance with Fixed RSS thresholds

In this section the behaviour of the system is validated for different fixed RSS threshold levels applied to all the APs. Three performance metrics were analysed, i.e. a) User session split among the three layers (LTE macro, LTE micro, WLAN); b) Average user throughput; c) 5th percentile user throughput.

The left plot in Figure 3 indicates that 87% of the users are served on WLAN for the minimal RSS threshold (-92dBm) level. This corresponds to the 'WLAN if coverage' scenario.

The number of users served on WLAN rapidly decreases with the increase of the RSS threshold. The sensitivity of user access selection to the RSS threshold is evident for WLAN and LTE micro layer. In contrast to this, the RSS threshold has a limited impact on the offered traffic in LTE macro layer since most of the WLAN coverage area is overlapped with the LTE micro layer.
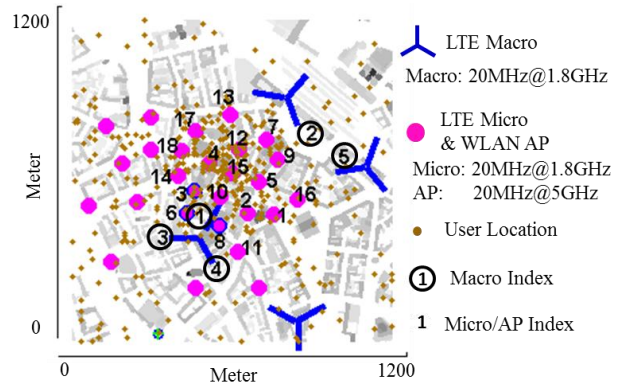

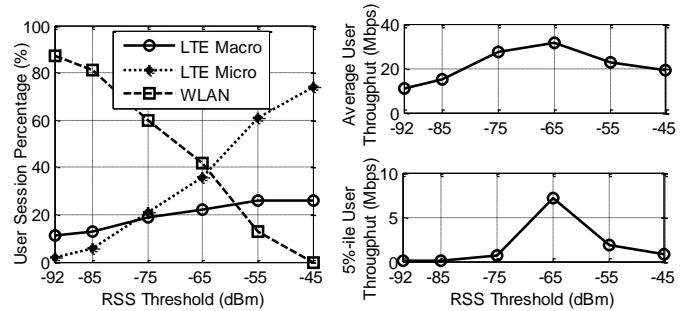**Figure 2: Evaluation scenario: network deployment and user locations**

Figure 3: Achieved user session percentage (left) and DL user throughput (right) versus the RSS threshold.

The peak performance of the average and 5th percentile throughput is achieved for the RSS threshold level of -65 dBm. For this threshold almost the same percentage of users are served on the WLAN and LTE micro layer.

V. SON Algorithm evaluation

A. SON parameter setting

The parameter setting for the SON algorithm evaluation is summarized in Table 1. The *RSS_Thr_Step*, $P_{SON}/P_L/P_W$ and α_L/α_W determine the frequency and magnitude of the *RSS_Thr* adjustment and different settings were investigated to study the sensitivity and stability of the algorithms.

Parameter	Description	Setting
P_{SON}	Periodicity of SON algorithm execution	{0.5, 1, 2} sec
p_L / p_W	Periodicity of LTE/WLAN load calculation	{0.5, 1, 2} sec / {0.5, 1, 2} sec
α_L / α_W	LTE/WLAN load filtering factor	{0.5,0.9} / {0.5,0.9}
Thr_High_LTE	High LTE cell load threshold	70%
Thr_High_WLAN	High WLAN AP load threshold	70%
Thr_Low_LTE	Low LTE cell load threshold	45%
Thr_Low_WLAN	Low WLAN AP load threshold	45%
RSS_Thr_Initial	Initial value of the RSS_Thr	-92 dBm
RSS_Thr_Step	Step size of RSS_Thr adjustment	{0.5, 1, 2} dB
RSS_Thr Min / Max	Minimum and maximum values of the RSS_Thr	-92 dBm / -45 dBm

Table 1: Adopted SON parameters.

B. Performance results and sensitivity to parameter settings

In this paper, the user experience is measured by the 5th percentile and average user throughput. The user throughput statistics obtained from simulations with the different SON parameter settings are summarized in Table 2. Two reference cases with fixed RSS thresholds are used for benchmarking. Only cells and APs covering the hot zone are included in the performance statistic collection (indexed in Figure 2).

All the SON cases had *RSS_Thr* initially configured to the 'WLAN if coverage' value, and achieved significant gains compared to the 'WLAN if coverage' reference case by steering users to the LTE layers. Among them, the SON algorithm with the reference settings has the best 5th percentile user throughput, which is 14% better than the best fixed threshold reference case.

The SON algorithm is not very sensitive to the load filtering factor. With smoother load filtering ($\alpha=0.5$), the user throughput has 8% degradation in the 5th percentile value and 4% gain in the average value. It indicates that the optimized average and 5th percentile user throughput may not be achieved at the same time with the same settings.

For the cases where the *RSS_Thr_Step* and $P_{SON}/P_L/P_W$ were configured to the slower update manner, obvious user throughput degradation was observed. In this case the WLAN user percentage is 13% higher than the reference settings. It suggests that the algorithm is too slow to follow load variations and reach a balanced load condition. On the other hand, the faster adjustment speed resulted in a slight decrease in the user throughput. These results imply that the performance of the SON algorithm may be affected by the traffic model which determines the fluctuation of the load. This aspect is further investigated in Section V-C.

Figure 4 shows the DL and UL user throughput cumulative distribution function (CDF) for the SON algorithm with the reference settings. The DL user throughput distribution of the three network layers, i.e. LTE macro, LTE micro and WLAN, is approximately identical when the user throughput is less than 20 Mbps. It indicates a balanced performance among the layers was achieved which optimized the overall user experience.
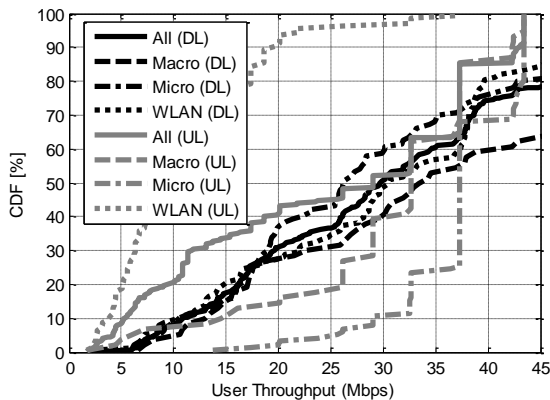
	5%-ile / Avg. user thrp. (Mbps)	WLAN users (%)
Reference: WLAN if coverage Fixed RSS_Thr = -92 dBm	0.1 / 11	87
Reference: Best Fixed Threshold Fixed RSS_Thr = -65 dBm	7.2 / 31.6	42
SON: reference settings $P_{SON}/P_L/P_W=1s$, RSS_Thr_Step=1dB, $\alpha=0.9$	8.2 / 31.7	41
SON: smooth load filtering $P_{SON}/P_L/P_W=1s$, RSS_Thr_Step=1dB, $\alpha=0.5$	7.5 / 33.1	45
SON: slow RSS_Thr update $P_{SON}/P_L/P_W=2s$, RSS_Thr_Step=0.5dB, $\alpha=0.9$	3.7 / 28.2	54
SON: fast RSS_Thr update $P_{SON}/P_L/P_W=0.5s$, RSS_Thr_Step=2dB, $\alpha=0.9$	7.1 / 31.2	38

Table 2: Performance of the reference cases and the SON algorithm with different settings.

Because the SON algorithm adopts the DL LTE load as the monitoring KPI, the UL user throughput is sub-optimal. The LTE network had much higher UL throughput since a dedicated 20 MHz band was allocated to the UL comparing to the WLAN where the DL and UL shared a 20 MHz frequency band. It is noticed that the WLAN UL throughput is lower than the DL since the UL transmission from a terminal almost always shared the radio channel with its own DL transmission due to the smaller uploading file size. Additional mechanism needs to be added to the SON algorithm to address the optimization of the UL user experience.

Since the SON algorithm acts upon the monitored load and adjusts the *RSS_Thr* accordingly, the load should be kept in the configured range by the algorithm and the *RSS_Thr* tuning should reflect the adjustment. Such insights are given in Figure 5. Comparing with the best fixed threshold reference case, the SON algorithm achieved a more balanced load between the two systems, e.g. higher *RSS_Thr* values were set for the co-sited AP/micro 3, 6, 10, 12, 14 and 15 therefore more traffic was steered to the LTE network to balance the load.

Figure 6 shows the adjustment of the *RSS_Thr* in time for AP 15. After an initial phase of approximately 60 seconds, the *RSS_Thr* became stabilized at about -55 dBm with a fluctuation of ±5 dB. Similar behaviour was observed in other APs as well.

Figure 4: User throughput distribution per network layer for the SON algorithm with the reference settings.
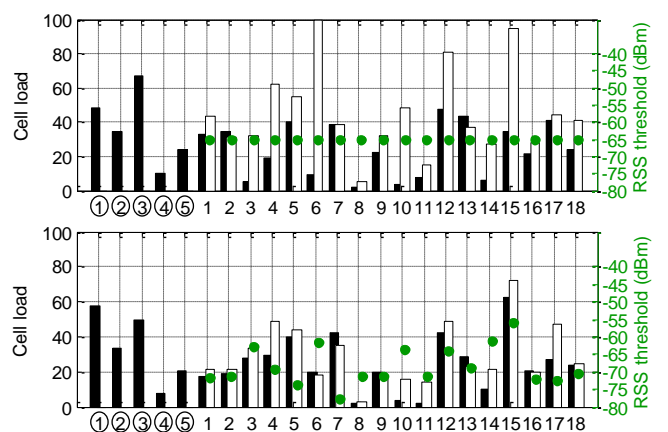

Figure 5: LTE Cell (black) and WLAN AP (white) load and RSS threshold for the best fixed threshold reference case (upper) and the SON algorithm with the reference settings (lower).
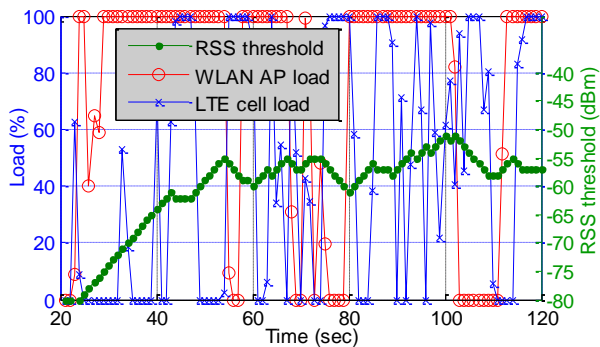
Figure 6: Time-trace of AP/Micro 15 for the SON algorithm: LTE cell / WLAN AP load and RSS threshold

C. Impact of traffic model parameters

The robustness of the SON algorithm to different traffic model settings is summarized in Table 3.

With the first three traffic model variances the overall offered traffic in the area was kept constant but the file size and user arrival rate were changed. With the smaller file sizes and larger user arrival rates, there is a higher probability that more users appear in the same cell or AP and share the radio channel. Since the WLAN efficiency decreases with multiple active users competing for the channel access, the SON algorithm steered more users to the LTE. This is proved by the WLAN user percentage listed in Table 3. On the other hand, the fixed - 65 dBm setting of the *RSS_Thr* was not optimal for the reconfigured traffic models and the performance gap between the fixed threshold and the SON algorithm became much larger.

For the larger file size, the SON algorithm failed to optimize the user throughput. It is likely that the large file size approaches a full buffer traffic model and the resource utilization is not an ideal load measure in this condition. Other measurements, e.g. required radio resources to serve the connected terminal with respect to total available resources or user throughput statistics, may be adopted to improve the SON algorithm in the case of large size file transfer.

A low load scenario is also simulated by reducing the overall offered traffic by half. The SON algorithm outperformed the fixed RSS threshold in the low load scenario in the 5th percentile user throughput.

[File size: DL/UL, User arrival rate]	SON with the reference settings		RSS_Thr = -65 dBm	
	5%-ile / Avg. user thrp. (Mbps)	WLAN users (%)	5%-ile / Avg. user thrp. (Mbps)	WLAN users (%)
Reference [5 MB/0.8 MB, 12]	8.2/31.7	41	7.2/31.6	42
[2.5 MB/0.4 MB, 24]	7.2/27.8	39	6.6/26.8	42
[1.25 MB/0.2 MB, 48]	5.8/23.1	34	3.9/21.8	42
[10 MB/1.6 MB, 6]	6.6/33.0	40	7.2/35.6	42
[5 MB/0.8 MB, 6]	10.7/38.1	48	8.3/40.1	42

Table 3: User throughput statistics with different traffic model settings

VI. CONCLUSION AND FUTURE WORK

In this paper, we proposed a RSS-based SON algorithm for access network selection between the LTE and WLAN systems with the target of user experience improvement. The algorithm adopts a WLAN RSS threshold to control the access selection, and the threshold is updated automatically based on periodically monitored load in both LTE and WLAN systems.

The SON algorithm was evaluated by simulations in realistic heterogeneous network scenarios with file downloading and uploading traffic. The simulation results proved that the SON algorithm successfully balanced the load between the two systems and optimized user throughput statistics with various traffic parameter settings.

The optimization of the SON parameters with respect to the traffic parameters is subject to further study. When the file size was large the algorithm became sub-optimal which suggests that the load measures need to be improved to reflect user experience more accurately in such conditions. The SON algorithm also needs to be evaluated with mobile users and/or mixed traffic types. Given such high dynamic scenarios, a benchmarking between the SON algorithm and real time per-user steering will provide further understanding to the potential and limitation of the SON solution. Furthermore, more understanding of the coexistence of distributed and centralized SON functions is needed to achieve a holistic solution and further optimize the performance.

VII. ACKNOWLEDGEMENT

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