Data Retention based low leakage power TCAM for Network Packet Routing

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Abstract: The proposed method holds significant theoretical significance. To address the power consumption challenges inherent in high-speed network packet routing. Leveraging sophisticated data retention strategies, this system optimizes the operation of TCAM modules, allowing for the retention of critical routing data while significantly reducing power consumption. This innovation is particularly crucial in today's demanding network environments, where efficiency and energy conservation are paramount. By implementing this approach, the proposed TCAM system not only ensures seamless and rapid packet routing but also contributes to a more sustainable and cost-effective networking infrastructure. This advancement marks a significant step forward in the evolution of routing technologies, promising enhanced performance and efficiency for modern communication networks.

Keywords: Network packet routing, Data retention, TCAM, Low leakage data retention.

I. INTRODUCTION

The proposed system represents a pivotal advancement in the realm of network packet routing .In the face of escalating demands for faster and more efficient data transmission, traditional TCAM modules have grappled with power consumption issues. The innovative system, however, introduces a paradigm shift by employing sophisticated data retention techniques. By selectively retaining critical routing information, achieves a remarkable reduction in power leakage, without compromising the integrity of essential data.

In doing so, it addresses a critical bottleneck in contemporary networking infrastructure, offering a compelling solution that not only enhances performance but also substantially reduces energy overheads. The introduction heralds a new era in routing technology, poised to revolutionize the efficiency and sustainability of modern communication networks.

To the escalating demands of today's high-speed networking environments. With data traffic volumes reaching unprecedented levels, conventional TCAM modules have struggled to balance performance with power efficiency. The proposed method approach strategically leverages advanced data retention strategies to mitigate power leakage while ensuring vital routing data remains readily accessible. The breakthrough not only translates into tangible benefits for energy-conscious network operators but also underscores a broader commitment to sustainable technology solutions in an era where environmental considerations are paramount. Its ability to finely balance power consumption and routing efficiency addresses a longstanding challenge in network infrastructure. As data volumes continue to surge, the demand for high-speed packet processing has never been greater. The system's innovative utilization of data retention not only optimizes power usage but also ensures rapid access to essential routing information. Beyond its immediate technical merits, this advancement holds the potential to revolutionize the broader landscape of network architecture, ushering in a new era of energy-efficient, high-performance routing solutions. In an age where sustainability is at the forefront of technological progress, this

TCAM system stands as a testament to the ingenuity and foresight driving the evolution of modern networking.

A new state-preserved technique, named data retention based TCAM (DR-TCAM), is proposed to reduce the leakage power dissipated in the TCAM memory. According to the continuous feature of mask data, the DR- TCAM can dynamically adapt the power source of mask cells so as to reduce the TCAM leakage power. Particularly, the mask data wouldn't be destroyed in the DRTCAM. Theproposed TCAM structure was designed and implemented using 45nm technology in Tanner EDA tool. Mobile Communication plays a very important role in modern life. With the progress of telecommunication technology, a large number of applications are designed, such as video stream, on-line game, navigation, etc., and many of them demand low communication latency, high throughput, and high data rate.Consequently, rapid packet routing and data searching are two fundamental requirements for 4G/5G network routers. Ternary content addressable memory (TCAM) has the featureof fast and parallel data searches. The routing table implemented with TCAM can easily achieve the goal of rapidrouting. However, this attractive feature would induce considerable leakage power since a large number oftransistors are used.

Ternary Content Addressable Memory (TCAM) is a specialized type of memory used in network devices for high-speed table lookups. In TCAM, data retention refers to the ability of the memory to store and maintain its content without power. Unlike traditional RAM (Random Access Memory), TCAM is non-volatile, meaning it retains its storeddata even when power is removed. This characteristic is crucial in networking applications where rapid table lookupsare required for tasks like routing and forwarding.

TCAM retains its data by using a combination of three statesfor each memory cell: 0, 1, and "don't care" (X or *). The "don't care" state allows TCAM to match any input bit duringa lookup, providing flexibility in matching patterns. In summary, TCAM has inherent data retention capabilities due to its non-volatile nature, making it well-suited for applications where quick and efficient table lookups are essential, even in the absence of continuous power.

II. PROPOSED TCAM DESIGN

A. *view of the Proposed 4 BIT tcam*

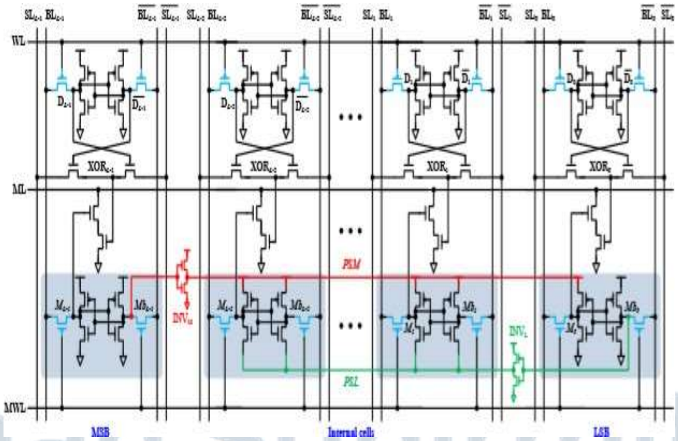


Fig 1 3D view of the Proposed TCAM

For example, the 32-bit TCAM entry is partitioned into 4 segments, each segment has 8 TCAM cells (L = 8, N =32, and S = 4).

1) Segments S1 and S2: In the all 1s segment, the PSM and PSL are both H so that the VDD paths and GND paths of internal SRAM cells are both set to VDD. This makes the internal cells' data M6 to M1 remaining 1, but the inverse data Mb6 to Mb1 are raised from 0 to 1. Because the voltage difference between VDD and GND path of the internal maskcells is minimized, the leakage power can be largely reduced.

2) Segment S4: In the all 0s segment, the VDD and GND paths of internal SRAM cells are both set to GND. This makes the internal cells' data M6 to M1 still remaining 0, butthe inverse data Mb6 to Mb1 are discharged from 1 to 0. Similarly, the leakage power consumption can be largely reduced.

3) Segment S3: In the boundary segment, the MSB M7 mustbe 1 and the LSB M0 must be 0.

Accordingly, the PSM and PSL are set to VDD and GND, such that the internal SRAM cells work as normal. No leakage power can be saved in this case.

B. Design of TCAM in tanner eda

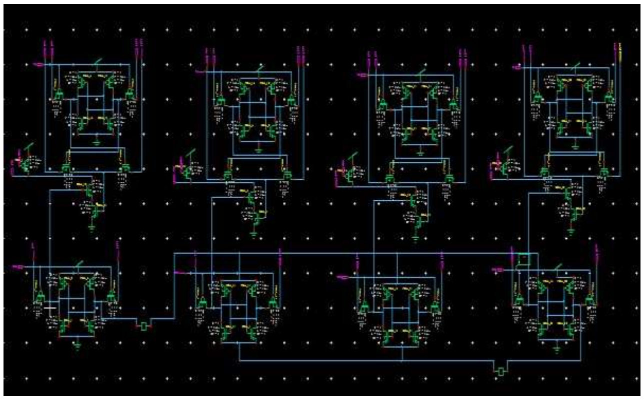


Fig 2 Design of TCAM in tanner eda tool

Implementing TCAM (Ternary Content Addressable Memory) involves integrating specialized memory hardware into networking devices like routers and switches. TCAM allows for high-speed packet forwarding and routing by enabling parallel search operations on stored data. Key steps in implementing TCAM include hardware design for ternary storage, array architecture optimization for fast searching, development of efficient search algorithms, integration with networking hardware, rigorous testing, and optimization for factors like power consumption and area utilization. Ultimately, TCAM implementation enhances network performance and scalability by enabling rapid and efficient lookup of forwarding information.

TCAM design and simulations

Leakage current paths of (a) the traditional SRAM, (b) the DR-TCAM internal mask cell in all 1s segment, and (c) the DR-TCAM internal mask cell in all 0s segment. dotted lines represent the gate leakage current *Igate* of NMOS. The blue solid and dotted lines represent *Isub* and *Igate* of PMOS, respectively. The detailed leakage power estimated by HSPICE with TSMC 40nm technology are summarized in TABLE below.

Fig. shows the leakage current paths of the DR-TCAM internal mask cell when the segment is all 1s segment. From Fig. and Table below, it is clear that in this case, the internal mask cell consumes very little leakage power for the reason that the voltage difference between 1V and 1 V can be ignored. Therefore, compared to the traditional SRAM cell, the leakage power saving of DR-TCAM's internal mask in all 1s segment is about 99%.

Fig. shows the leakage current paths of the DR-TCAM internal mask cell when the segment is all 0s segment. In Fig. the leakage currents of transistors P1, P2, N1, and N2 can be minimized because the sources and drains of these transistors are all set in 0V. However, the *Isub* of T2 would increase compared with the traditional design, and cancel out a little leakage power saving from other transistors. As shown in above Table, the leakage power saving achieves 71% for the internal mask cell in all 0s segment.

SRAM (single cell)	Leakage Power (Watt)		Reduction Percentage	
	all 1s seg.	all 0s seg.	all 1s seg.	all 0s seg.
(a) Traditional SRAM	2.060e-08	2.060e-08	-	-
(b) DR-TCAM Internal SRAM	1.4 54e-10	5.973e-09	99.29%	71.00%
(c) DR-TCAM LSB SRAM	1.681e-08	1.592e-08	18.40%	22.72%

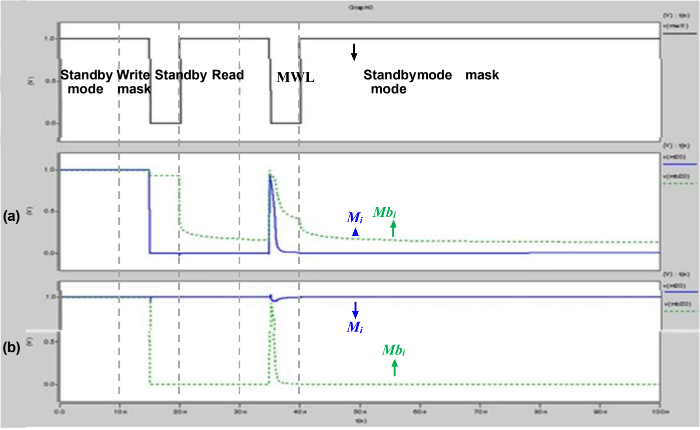


Fig 3 The correct waveforms for all 1s segment being written and changed into (a) all 0s segment, and (b) boundary segment.

III EXPERIMENTAL RESULTS

In this paper, all TCAM designs are implemented with TSMC 40nm technology and simulated with HSPICE in 25˚C and 1.0V power supply. The TCAM size is 1024 32, which means that there are 1024 entries, and each entry is 32-bit.

A. Functionality Of Dr-Tcam

To verify the DR-TCAM write and read function in standby(low-leakage) mode, we first write the mask data, and then read them after 10ns. Fig. 4 shows the case of all 1s segment. From Fig. , it is clear that an all 1s segment can be written and changed into all 0s segment successfully, and then the data can be read correctly. Besides writing all 0s, the DR- TCAM can also perform the successful write from all 1s segment to the boundary segment, as shown in Fig. Similarly, Fig. 4 shows the correct waveforms for all 0s segment being written and changed into all 1s segment and boundary segment, respectively. Therefore, the functionality of DR-TCAM design is verified and works well while reducing leakage power consumption.

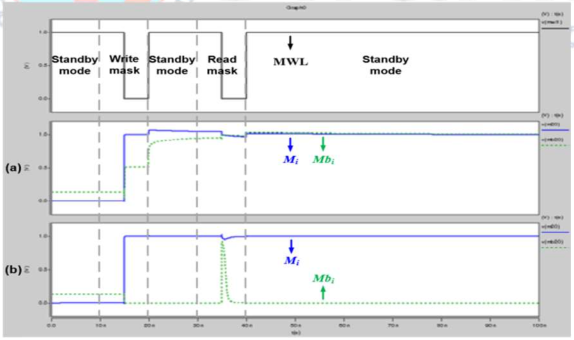


Fig. 4. The correct waveforms for all 0s segment being written and changed into (a) all 1s segment, and (b) boundary segment.

TABLE I shows the detailed results, including the leakage power consumption and total power consumption of each TCAM. The average power reduction is further illustrated in Fig. 5, from which all TCAM designs can effectively reduce the leakage power consumption compared to the traditional TCAM. Among them, the DR-TCAM and TSSG-TCAM reduce much leakage power than the others, i.e., 41% and 30%, since the continuous feature of mask data is utilized in both of these two TCAM designs.

For total power consumption, the TSSG-TCAM and the DRTCAM can save 7% to 12% total power, but the DPS- TCAM and the MVC-TCAM consume much more total power than the traditional TCAM. In TABLE I, all TCAM architectures are designed for the goal of low leakage power consumption; however, the total power consumption is composed of dynamic power and leakage power

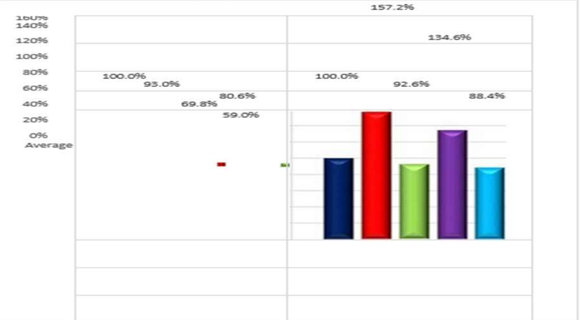
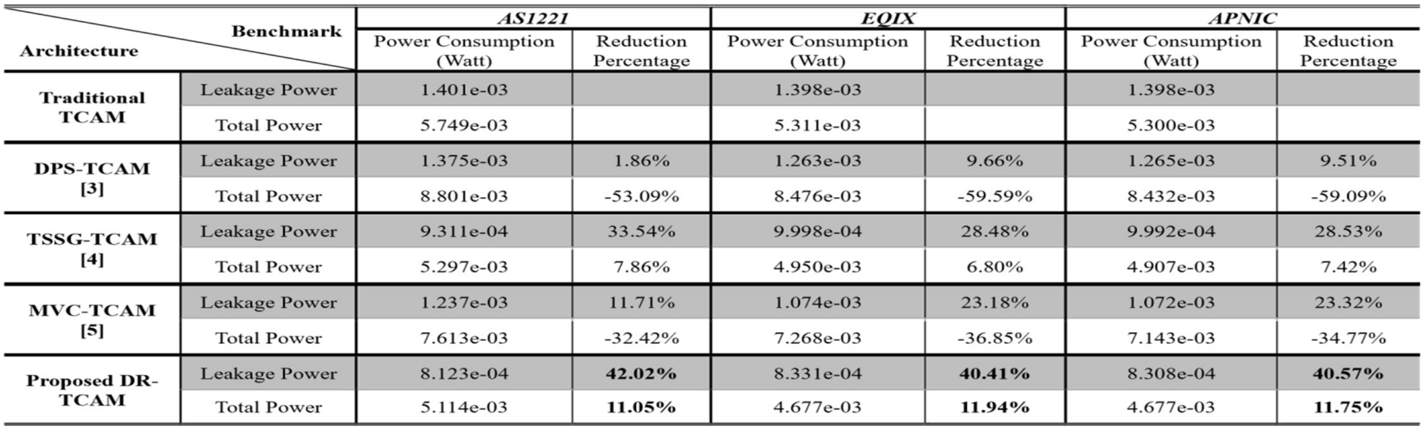


Fig. 5. Average power reduction for all TCAMdesigns.

B. Leakage and Total Power Reduction

For a real data distribution, three routing table benchmarks from BGP Report [7], including AS1221, EQIX, and APNIC, are used to examine all TCAM designs. To highlight the superiority of DR-TCAM in leakage power reduction, besides the traditional TCAM design, three low-leakage designs, including DPS-TCAM [3], TSSG-TCAM [4], and MVC-TCAM [5], are also implemented and simulated with the same condition for comparison. Note that for a fair comparison, the best case of each TCAM is selected, i.e., DPSGND for DPSTCAM [3], 8(24) partition for TSSG-TCAM [4], and MVC_Seg32 for MVC-TCAM [5]. In our previous evaluation, DR-TCAM demonstrates the best result when segment size is 8-bit (Seg8). Thus, the best configuration of DR-TCAM is Seg8

TABLE I THE POWER CONSUMPTION OF LOW LEAKAGE TCAM DESIGNS



Benchmark / Architecture		AS1221		EQIX		APNIC	
		Power Consumption (Watt)	Reduction Percentage	Power Consumption (Watt)	Reduction Percentage	Power Consumption (Watt)	Reduction Percentage
Traditional TCAM	Leakage Power	1.401e-03		1.398e-03		1.398e-03	
	Total Power	5.749e-03		5.311e-03		5.300e-03	
DPS-TCAM [3]	Leakage Power	1.375e-03	1.86%	1.263e-03	9.66%	1.265e-03	9.51%
	Total Power	8.801e-03	-53.09%	8.476e-03	-59.59%	8.432e-03	-59.09%
TSSG-TCAM [4]	Leakage Power	9.311e-04	33.54%	9.998e-04	28.48%	9.992e-04	28.53%
	Total Power	5.297e-03	7.86%	4.950e-03	6.80%	4.907e-03	7.42%
MVC-TCAM [5]	Leakage Power	1.237e-03	11.71%	1.074e-03	23.18%	1.072e-03	23.32%
	Total Power	7.613e-03	-32.42%	7.268e-03	-36.85%	7.143e-03	-34.77%
Proposed DR-TCAM	Leakage Power	8.123e-04	**42.02%**	8.331e-04	**40.41%**	8.308e-04	**40.57%**
	Total Power	5.114e-03	**11.05%**	4.677e-03	**11.94%**	4.677e-03	**11.75%**

C. Search Performance

TABLE II shows the search latency of different TCAM designs. Compared to the traditional TCAM, the search overhead of the TSSG-TCAM is 2.03% and the search overhead of the DR-TCAM is 1.11%. Both of the DR-TCAM and TSSG-TCAM have performance penalties less than 2.50%, since the evaluation logics of these two TCAMs are the same as the traditional TCAM. However, the search-enable scheme discharges much MLs' capacitances than the traditional TCAM, and results in longer search latency.

TABLE II THE SEARCH LATENCY OF DIFFERENT TCAM DESIGNS

Architecture	Latency(ps)	Overhead
Traditional TCAM	79.39	-
DPS-TCAM [3]	83.83	5.59%
TSSG-TCAM [4]	81.00	2.03%
MVC-TCAM [5]	84.27	6.15%
DR-TCAM	80.27	1.11%

IV CONCLUSION AND FUTURE STUDIES

In this paper, we propose a low leakage TCAM design, called DR-TCAM. By using the continuous feature of mask data, the DR-TCAM can minimize the voltage difference between VDD and GND of internal mask cells so as to minimize the leakage power consumption. Unlike the previous TCAM designs, in the DR-TCAM all data can be preserved even inthe standby mode. The simulation results show that the DR- TCAM outperforms the related techniques in power reduction and search performance. Compared to the traditional design the DR-TCAM can reduce 41% leakage power with only 1.1%search performance loss.

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