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ACA-CSU: A Carry Selection Based Accuracy Configurable Approximate Adder

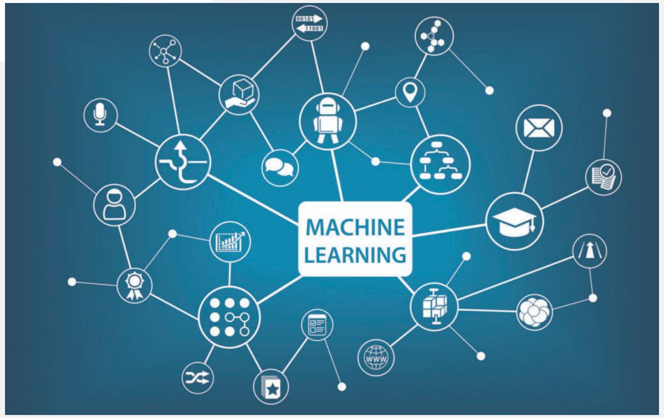
Alish Kanani
Department of Electrical Engineering
Indian Institute Of Technology, Jodhpur
Jodhpur,India
kanani.1@iitj.ac.in

Jigar Mehta,Neeraj Goel*
Department of Computer Science And Engineering
Indian Institute Of Technology, Ropar
Ropar,India
2018csb1155@iitrpr.ac.in , neeraj@iitrpr.ac.in

MOTIVATION

Accurate computation is the key of hardware design.

In some domains Approximation in basic computation does not impact much in overall accuracy of the application



Adder is the fundamental block for most computations

INTRODUCTION

Adaptive accuracy is important

Key idea: Adaptive length of carry chains

Our proposed gives the desirable accuracy in the least possible execution time.

ACCURACY CONFIGURABLE DESIGN

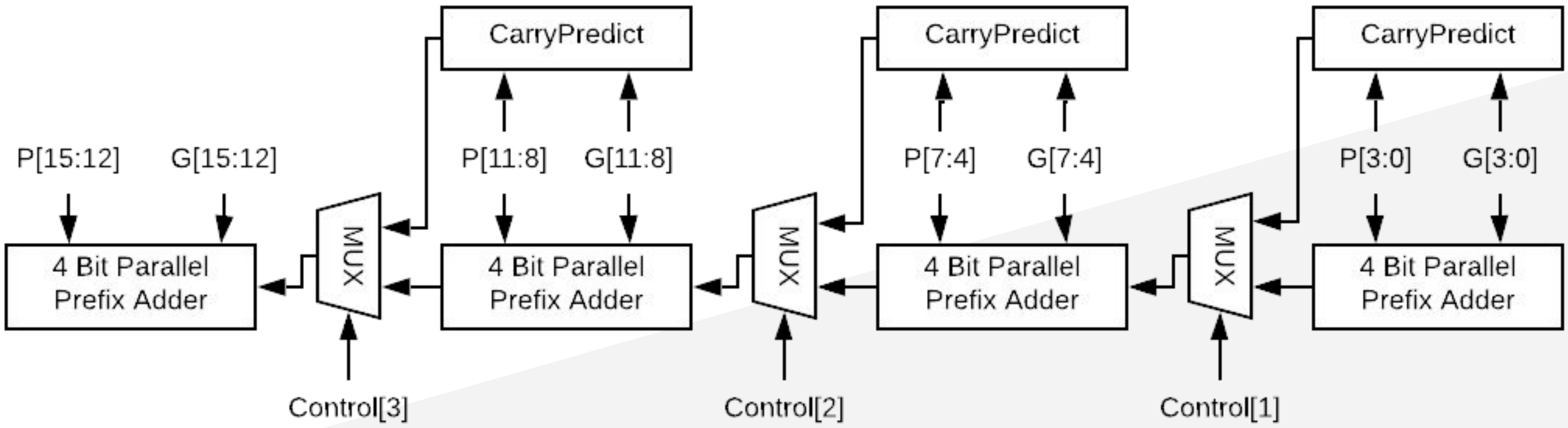


Fig. 1: Block diagram of 16 bit Accuracy Configurable Adder

OVERALL DESIGN OF ACA-CSU

- Maximum carry chain length of an m-bit prefix adder is m.
- CarryPredict takes K previous bits, thus accuracy of the sum block increases to K + M bits long carry chain.
- Adding one more Generate in the calculation of CPredict increases the accuracy of the adder.
- If Block Propagate (BP) is 1, carry is not generated by CarryPredict block thus, previous Generate is passed as carry.
- It increases the accuracy of the sum block to K+M+1 bits long carry chain.

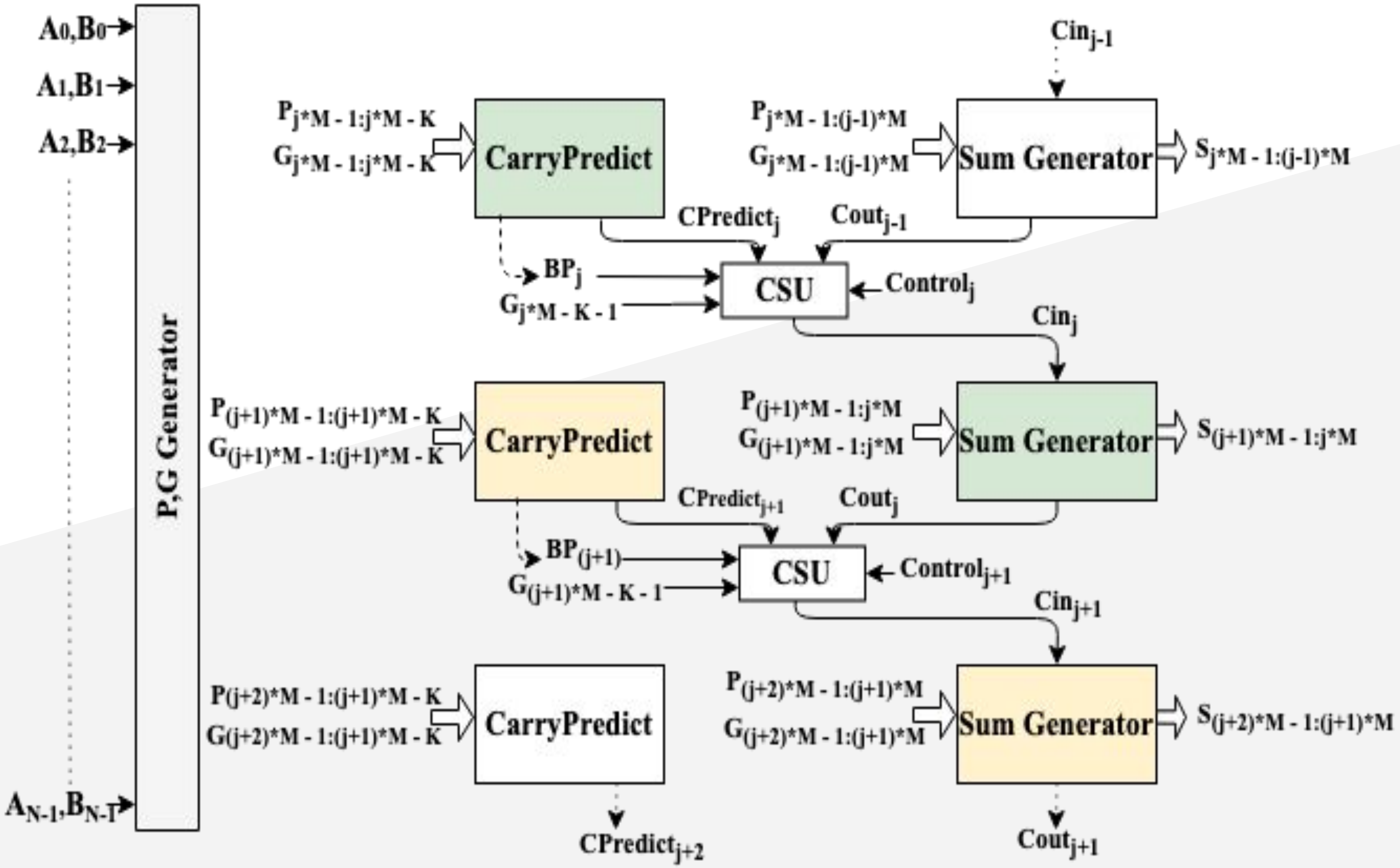


Fig. 2: Schematic of proposed ACA-CLA Adder

DESIGN OF CARRY SELECT UNIT

- Carry Select Unit takes $Control_j$, $CPredict_j$,$Cout_j$,$G_{j*M-K-1}$ and BP_j as input and gives Cin_j as output.

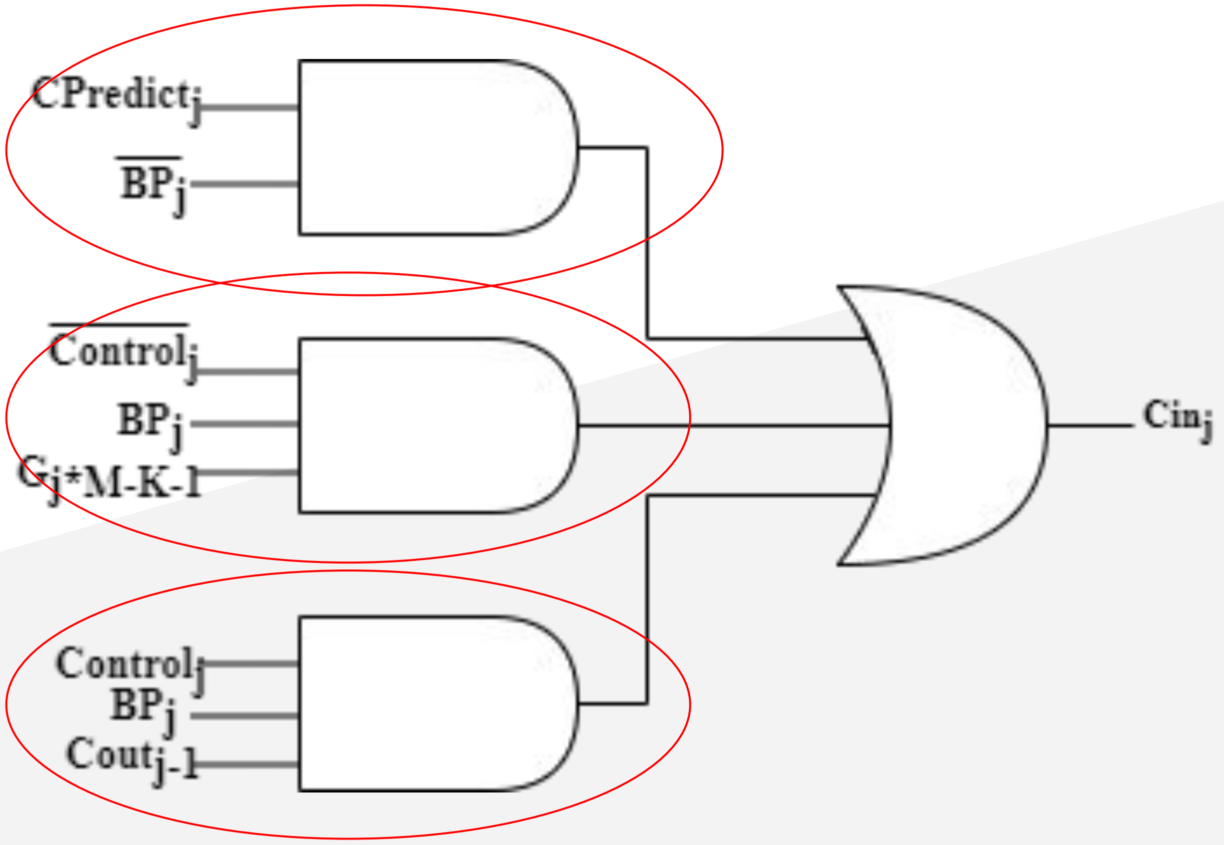


Fig 3: Gate level implementation of Carry Select Unit

THEORETICAL ERROR PROBABILITY

Block size of Sum Generator(M) and CarryPredict(K) are kept same. If there are (N/K=l) Sum Generator blocks then there will be (l−1) CarryPredict units.

PCR_i represents probability that $CarryPredict_i$ is wrong.
PCW_i represents the probability $CarryPredict_i$ is wrong given $CarryPredict_{i-1}$, $CarryPredict_{i-2}$, ..., $CarryPredict_1$ are right.

$$Pr(E) = PCR_2 + \sum_{i=3}^{l-1}(\prod_{j=2}^{i}\overline{PCR_j})PCW_i$$

$$PCR_2 = (\frac{1}{2^{K+1}})(\frac{1}{4})(1+\frac{1}{2}+\frac{1}{4}+...+\frac{1}{2^{K-2}}) = (\frac{2^{K-1}-1}{2^{2K+1}})$$

$$PCW_i = (\frac{1}{2^{K+1}})(\frac{1}{4})(1+\frac{1}{2}+\frac{1}{4}+...+\frac{1}{2^{K-1}}) = \frac{2^{K}-1}{2^{2K+2}}$$

$$Pr(E) = (\frac{2^{K-1}-1}{2^{2K+1}}) + (1-\frac{2^{K-1}-1}{2^{2K+1}})(\frac{2^{K}-1}{2^{2K+2}})(\sum_{i=1}^{l-2}(1-\frac{2^{K}-1}{2^{2K+2}})^{i-1})$$

ERROR RATE

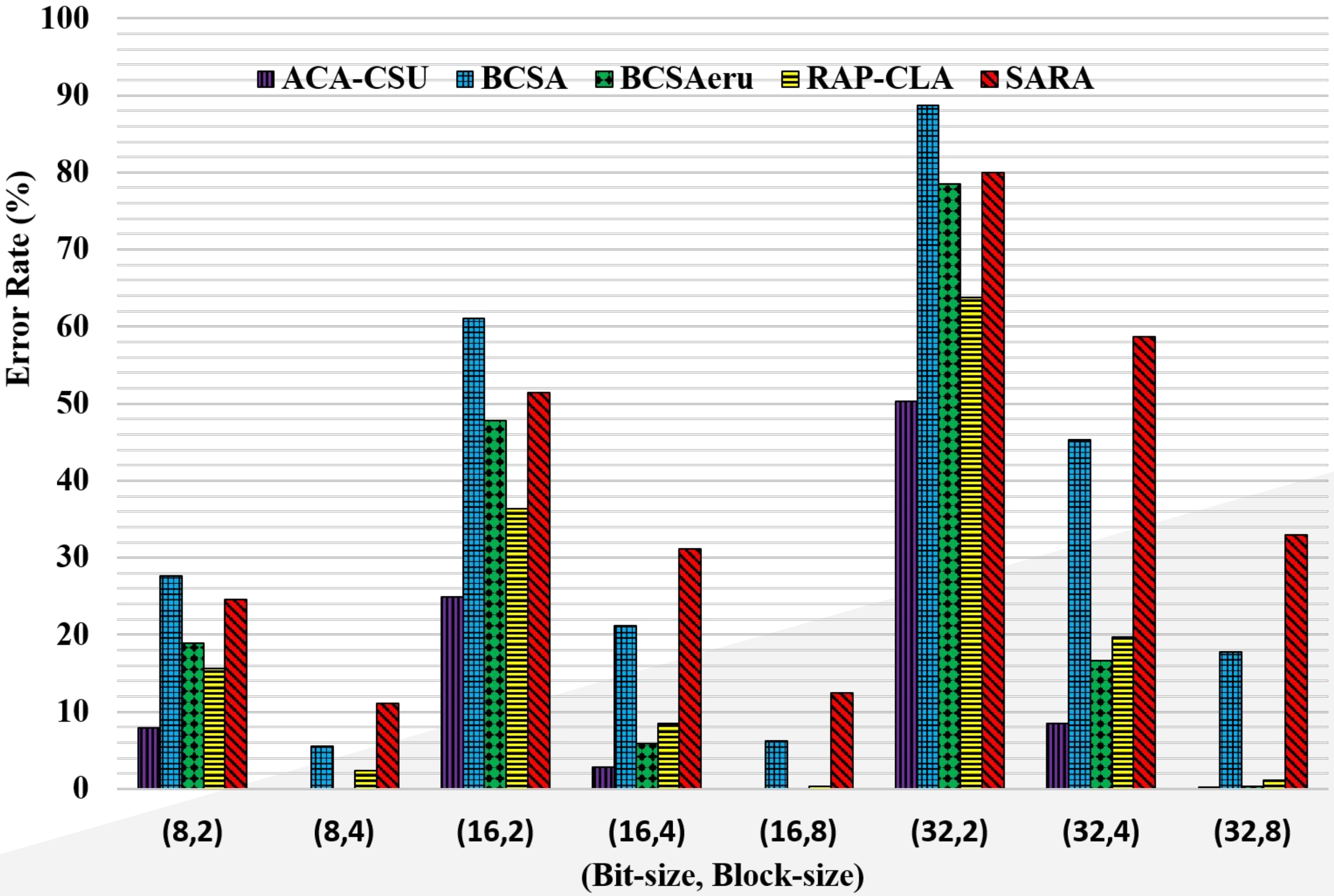


Fig 4: Error Rate Comparison of proposed ACA-CSU in its most approximate mode with previously implemented designs.

$$Pr(E) = \left(\frac{2^{K-1}-1}{2^{2K+1}}\right) + \left(1 - \frac{2^{K-1}-1}{2^{2K+1}}\right)\left(\frac{2^{K}-1}{2^{2K+2}}\right)\left(\sum_{i=1}^{l-2}\left(1 - \frac{2^{K}-1}{2^{2K+2}}\right)^{i-1}\right)$$

Theoretical value of Probability of an erroneous calculation in most approximate state, Pr(E)

NORMALIZED ERROR DISTANCE (NED)

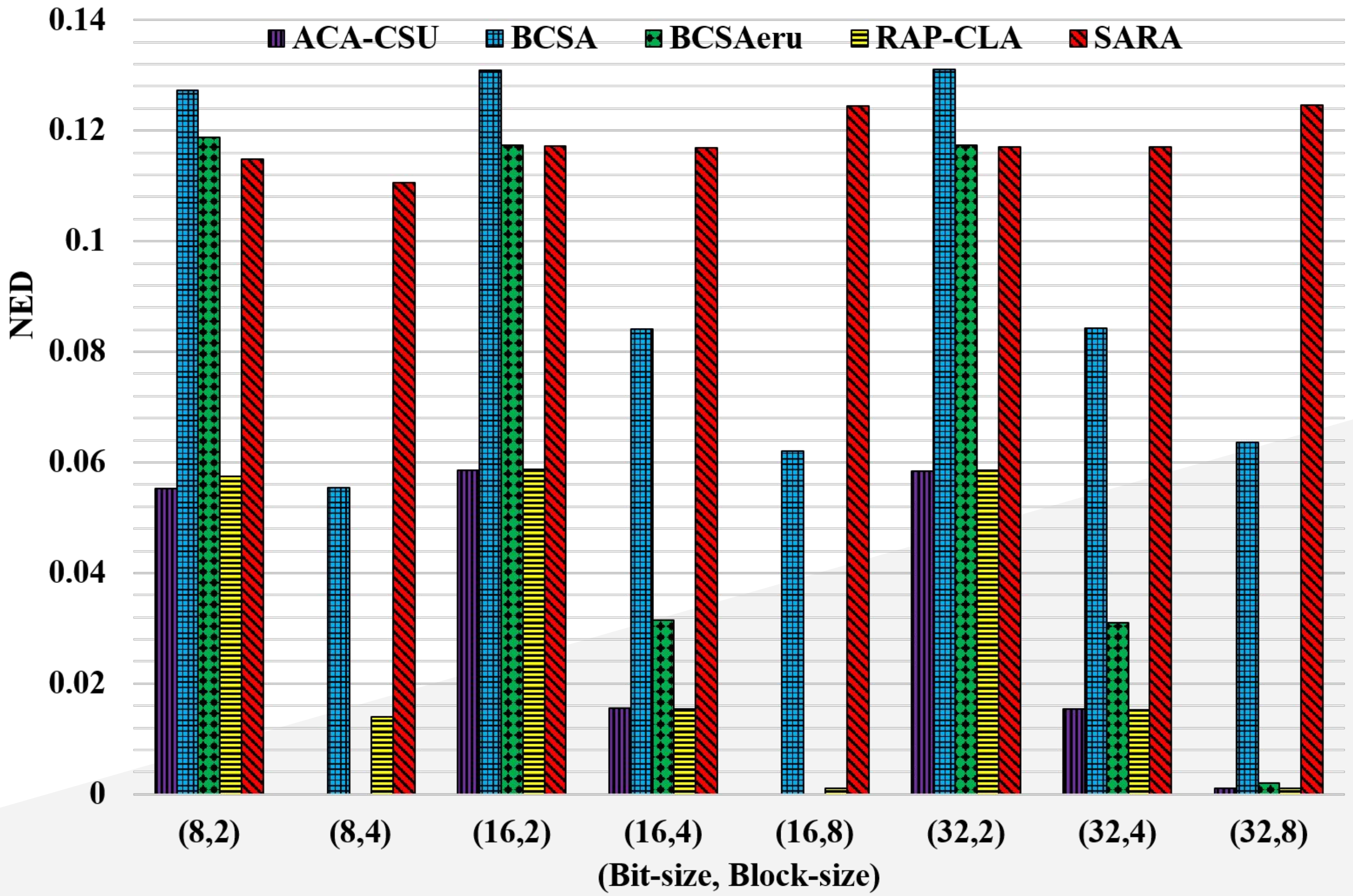


Fig 5: NED Comparison of proposed ACA-CSU in its most approximate mode with previously implemented designs.

Normalized Error Distance is a nearly invariant metric independent of the size of the adder.

It is useful in characterizing the reliability of a specific design.

The graph is plotted considering all input values to be equally likely.

MEAN RELATIVE ERROR DISTANCE (MRED)

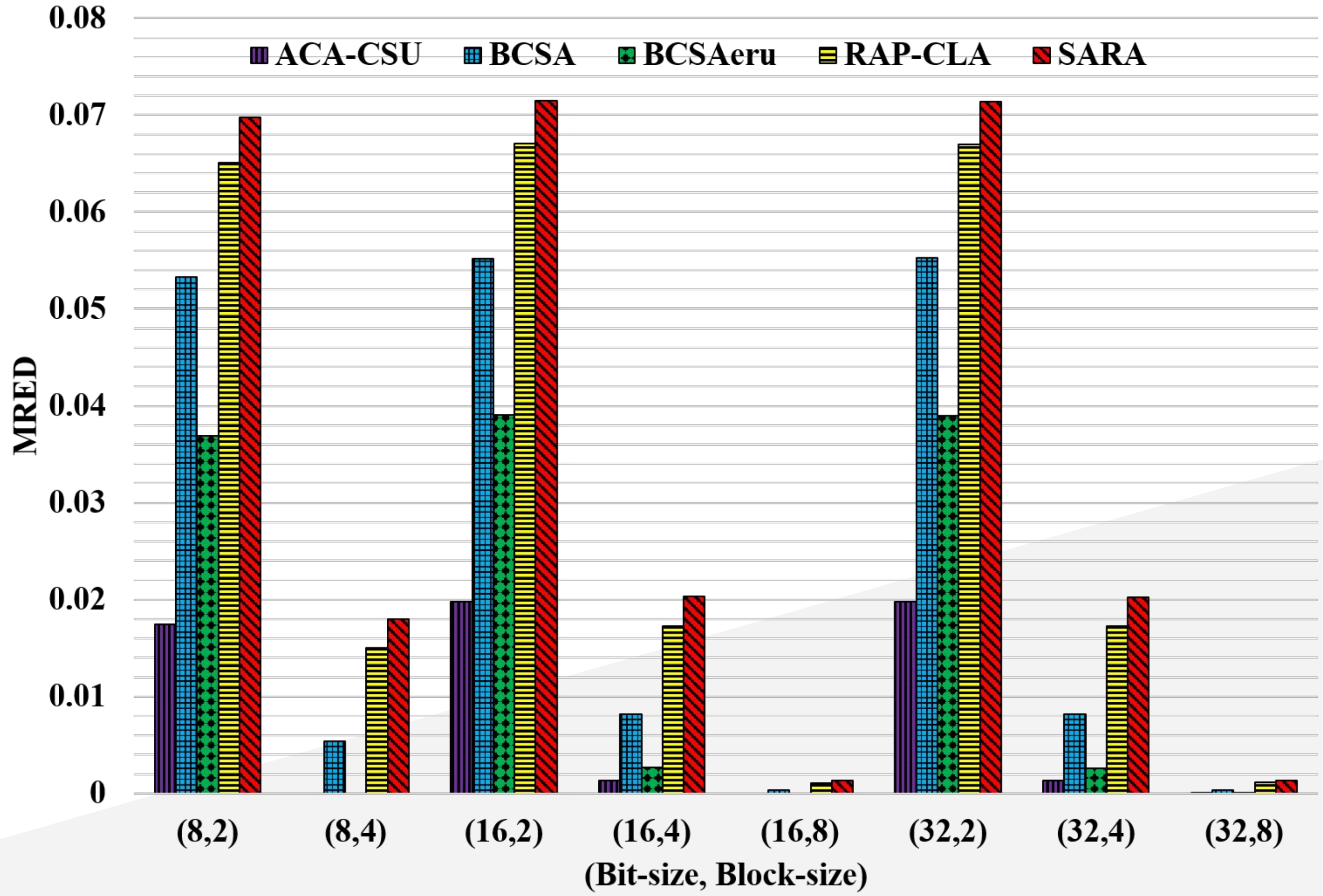


Fig 6: MRED Comparison of proposed ACA-CSU in its most approximate mode with previously implemented designs.

Mean Relative Error Distance is a measure of precision.

It is the mean of product of probability of a particular input and the relative error at that input value.

The graph is plotted considering all input values to be equally likely.

DELAY ANALYSIS

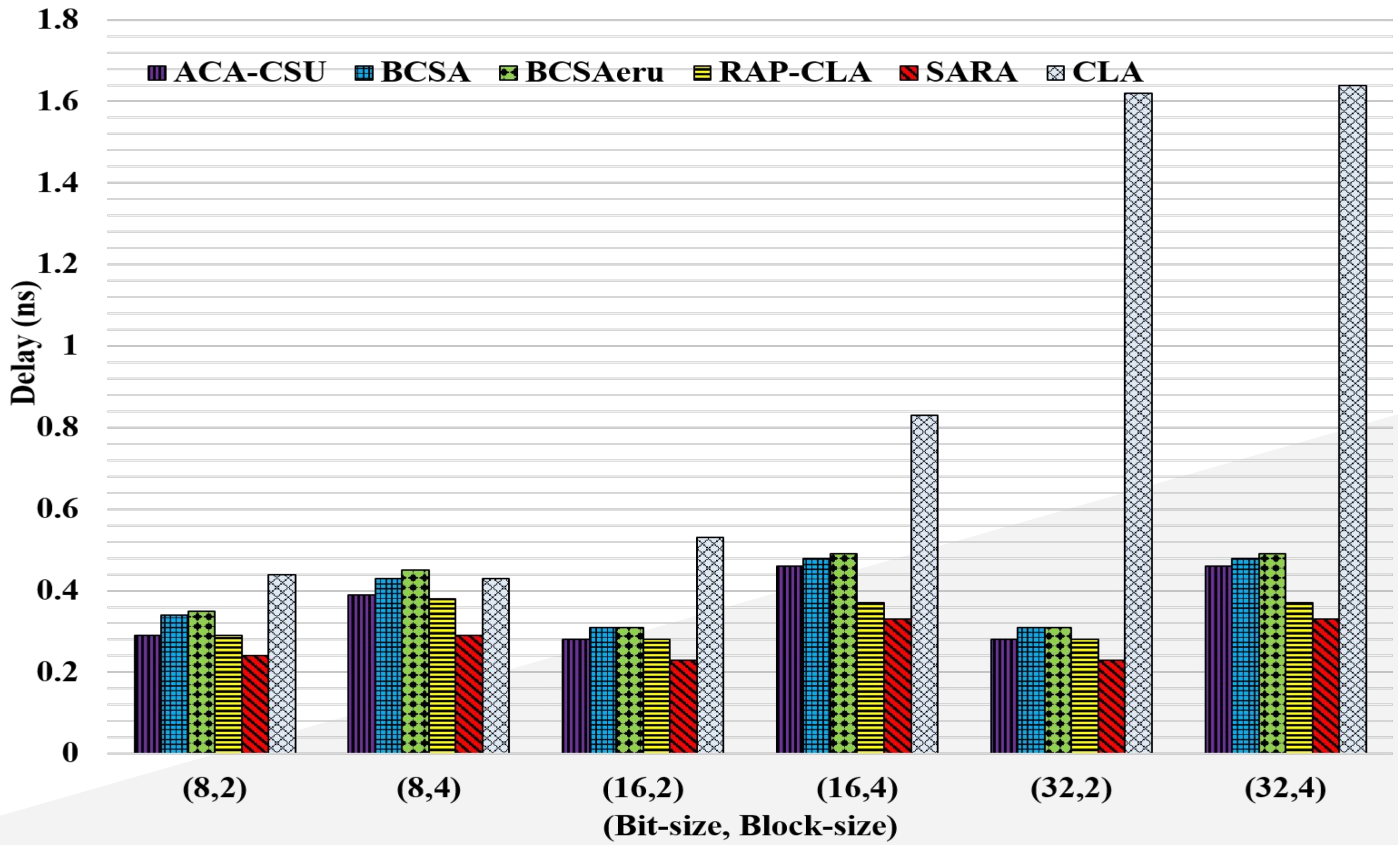


Fig. 7: Comparison of Delay of ACA-CSU in it's most approximate mode with previously implemented approximate adders.

In Accurate Mode, delay of the ACA-CSU is L*(delay of M-bit parallel prefix adder) + (L-1)*(delay of CSU). In most approximate mode, delay of the adder is (delay of M-bit parallel prefix adder) + (delay of CSU) + (delay of CarryPredict). Delay of CarryPredict depends on K.

IMPLEMENTATION: IMAGE PROCESSING

The following Image shows how a Gaussian Smoothing filter applied to the same image using different approximate adders looks like:

Fig. 8: Gaussian image smoothing: (a) Original image with noise, (b) Original filter, (c) Filter with rounded fixed point number, PSNR = 37.9761dB & SSIM = 0.95, **(d) ACA-CSU**, PSNR = 37.9123dB & SSIM = 0.9495,**(e) BCSA**, PSNR = 33.9086dB & SSIM = 0.9142, **(f) BCSAeru**, PSNR = 37.8372dB & SSIM = 0.9482, **(g) RAP-CLA**, PSNR = 29.3660dB & SSIM = 0.7814,**(h) SARA**, PSNR = 26.79dB & SSIM = 0.7870.

CONCLUSION

Accuracy has a trade-off with area and delay

The proposed CSU-ACA adder is the most accurate adder among the state of the art approximate adders

The proposed adder can trade-off delay with accuracy

The proposed adder can be used in image processing applications without any loss of accuracy