TABLE 1: RO BASED PUF AND SENSOR TOPOLOGY

Sl. No.	Types of PUF		Methodology	Conclusion
1	RO PUF [16]		A group of RO is used to measure CRP	• Pair of RO with lower frequency of separation led to degradation in reliability. • Presence of large number of RO led to area overhead and oscillation mode of all individual RO during CRP extraction makes the power budget of RO PUF critical.
2	CRO PUF [18]		• Similar to RO PUF, but RO section is replaced with CRO • In a group of k-pair of RO, only a pair with maximum frequency separation is selected to produce reliable response bit.	• Enhances reliability against temperature variation. • Unused pair of RO with lower frequency of separation are not considered, hence less number of CRPs. • Area overhead due to added temperature compensating module.
3	Hybrid RO [25]		RO is designed by cascading positive and negative temperature co-efficient inverter to lower the frequency deviation against temperature variation.	
4	Current starved inverter based RO [26]		Family of current starved inverter with temperature invariant biasing is used.	
5	Aging compensation techniques	RO using FTL inverter [27]	FTL based inverter is used rather than conventional CMOS inverter to lower the impact of NBTI.	• Reliability degradation due to both temperature variation and aging is improved. • Area overhead due to use of additional circuit module.
6		CRO using Aging Tolerant RO (ARO) [28]	Additional NMOS per inverter is used to lower the impact of NBTI	
7		Aging Resilient Current Starved inverter based RO (ACRO) [29]	Aging compensation module includes a MUX with PMOS and NMOS to lower NBTI.	
8		CRO with reduced supply voltage [31]	The RO section is driven by a reduced supply voltage ($V_{DD} – V_t$) to lower the impact of NBTI.	
Sl. No.	**Types of RO sensor**		**Methodology**	**Conclusion**
1	Conventional RO sensor [13]		• Frequency comparison between a pair of reference and stress RO predict the duration for which IC under test is used. • The RO is designed by using conventional CMOS logic	Can detect the ICs used for months
2	Accelerated Aging Mechanism	N-CDIR sensor [32]	Impact of NBTI on stress RO is accelerated by using NBTI aware RO.	Can detect the ICs used few weeks
3		AN-CDIR sensor [32]	Multiple pair of RO with NBTI accelerate feature is used as reference and stress RO rather than a single pair of RO.	Can detect the ICs used few days
4		RO sensor [34]	Voltage control section enable different amount of NBTI stress on reference and stressed RO.	Can detect the ICs used few weeks

TABLE 2 FUNCTIONAL MODE IN RO SENSOR

Mode	Function	
0	Both ROs are in sleep Mode	
1	$(RO)_{STR}$ is in stress mode (subjected to NBTI) and $(RO)_{REF}$ remains in sleep mode (free from NBTI)	
2	Authentication Mode (Frequency Comparison)	frequency of ROs in stress module is measured
3		frequency of ROs in reference module is measured

TABLE 3 SUPPLY VOLTAGE VARIATION IN PROPOSED INVERTER

$[C_s\, C_g]$	Operating voltage of RO
00	V_{DD}, V_t
01	V_{DD}, GND
10	$V_{DD}-V_t$, V_t
11	$V_{DD}-V_t$, GND

TABLE 4 FREQUENCY DEGRADATION AGAINST AGING

Types of RO	Aging Feature	% of degradation in f_{osc} after 20 year	No. of extra MOS/ inverter
Conventional CMOS RO [18]	-	26.61	-
ARO [28]	Lower NBTI	9.42	2
NBTI-aware RO [32]	Accelerate NBTI	40.81	3
RO driven by reduced supply voltage [31]	Lower NBTI	2.81	1
Proposed CRO	Lower NBTI stress (C_s=1)	1.111	4
	Higher NBTI stress (C_s=0)	45.74	

TABLE 5 PERFORMANCE COMPARISON (IN %) OF PUF

A. Security Metrics		Conventional CRO PUF [18]	ARO based CRO PUF [28]	CRO PUF with reduced supply voltage [31]	Proposed CRO PUF	Ideal value
Uniqueness		43.06	45.97	48.01	48.95	50%
Reliability	Temperature variation	91.817	-	94.54	96.984	100%
	Aging	91.284	93.322	94.421	97.825	
Uniformity		46.79	46.19	46.92	48.88	50%
SAC		47.16	46.44	47.31	49.01	50%
B. VLSI Metrics						
Power <in mW>		20.251	10.455	6.322	5.081	-
Area <in µm^2>		656.22	782.732	398.62	292.45	-

TABLE 6 RELIABILITY AGAINST BEST AND WORST CHALLENGE PATTERN

Challenge Pattern			Temperature variation	Aging
Selection Line	$[C_{s1}\, C_{s2}\, C_{s3}]$	$[C_{g1}\, C_{g2}\, C_{g3}]$		
Worst case	[000]	[XXX]	95.18	96.011
Best case	[111]	[XXX]	99.062	99.48

TABLE 7 RELIABILITY (IN %) OF PROPOSED CRO PUF ~ NUMBER OF CRO

No. of CRO	Reliability	
	Temperature variation	Aging
64	96.984	97.825
1024	96.027	97.162

TABLE 8 PERFORMANCE COMPARISON OF RO SENSOR

Types of RO sensor	Aging duration <in Days>					Area <in µm^2>
	T=0 D	T=2 D		T=4 D		
	µ	µ	% m	µ	% m	
AN-CDIR sensor [32]	0.384	1.847	4.56	2.266	0	9068.254
Proposed CRO sensor	0.214	2.312	1.03	3.181	0	1415.645