# TNT: How to Tweak a Block Cipher

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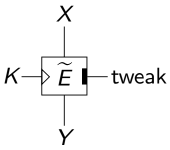
# Outline

Background: Tweakable Blockciphers (TBCs)

Our Contribution: Hybrid Approach – TNT Mode and TNT-AES

# Background - Tweakable Blockciphers (TBCs)

- Tweakable Blockcipher (TBC): a blockcipher with an additional input – the *tweak*.



- Why TBC? – Multiple independent blockciphers for modes of operation.

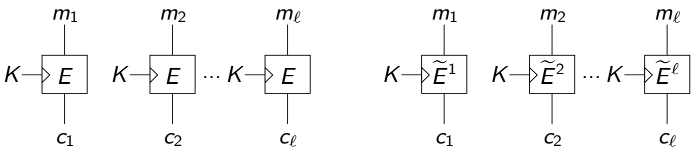


**Figure:** ECB using a TBC (the core of ΘCB3)

# Background - Beyond-Birthday-Bound (BBB) Security

Birthday-bound security $2^{n/2}$: consequences

- the mode (TBC mode, encryption mode, etc.) is secure only when the number of processed data blocks is less than $2^{n/2}$;
- 64-bit legacy blockciphers 3DES, $n = 64$: less than $2^{32}$ data blocks, practically vulnerable [BL16];
- 128-bit blockciphers AES: less data that can be securely processed, more frequent key update [GL17].

Hence, the needs of modes providing Beyond-Birthday-Bound (BBB) security are emerging.

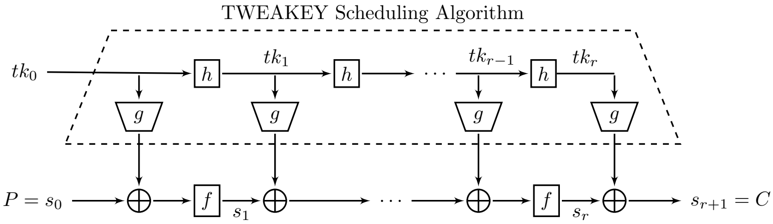
# Modular Approach: TBCs from Block Ciphers

TBCs from modes of operation

- Better understanding of the security: we know in clear that *when* it is insecure and *why* it is insecure.
- Usually less efficient than dedicated algorithms.
- Existing modes:
  - ⋆ Birthday-bound: LRW1, LRW2, XEX, $\widetilde{F}[1]$
  - ⋆ BBB: cascaded LRW2 (CLRW2), $\widetilde{F}[2]$, $\widetilde{E1}, \ldots, \widetilde{E32}$, XHX, XHX2

# Dedicated TBCs: Development

- Early design: Mercy [Cro00]
- Tweakey framework [JNP14b]: Deoxys-BC [Jea+14], SKINNY [Bei+16b], Kiasu [JNP14a]



- Security guarantees come from comprehensive cryptanalysis.
- Simpler retweaking?

# Outline

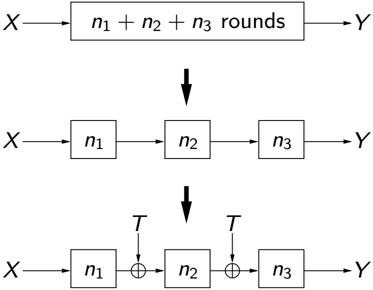
Background: Tweakable Blockciphers (TBCs)

Our Contribution: Hybrid Approach – TNT Mode and TNT-AES

# New Approach to Dedicated TBCs

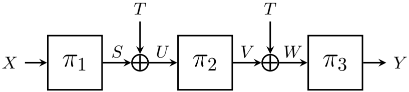
Tweak-aNd-Tweak: a new approach to reliable dedicated TBCs

1. Cut an iterative blockcipher into 3 chunks
2. XOR the tweak at the two cutting points



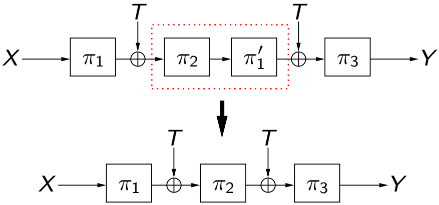
# New Approach to Dedicated TBCs

1. Cut a blockcipher into 3 chunks & add the tweak twice.
2. The underlying mode: Tweak-aNd-Tweak (TNT)



# New Approach to Dedicated TBCs

1. Cut a blockcipher into 3 chunks & add the tweak twice.
2. The underlying mode: Tweak-aNd-Tweak (TNT)
   Cascaded LRW1 or TNT:



- ⋆ LRW1 is only CPA secure up to birthday $2^{n/2}$ queries;
- ⋆ *Is* TNT *secure up to beyond-birthday* $2^{2n/3}$ *queries?*

# New Approach to Dedicated TBCs

1. Cut a blockcipher into 3 chunks & add the tweak twice.
2. The underlying mode: Tweak-aNd-Tweak (TNT)
   - ⋆ Security $2^{2n/3}$ goes beyond the birthday bound $2^{n/2}$
   - ⋆ Proved via the $\chi^2$ method [DHT17]:

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Our main intermediate result: Given $\ell - 1$ tuples of queries and responses $Q_{\ell-1} = (T_1, X_1, Y_1), \ldots, (T_{\ell-1}, X_{\ell-1}, Y_{\ell-1})$, two conditional probabilities are sufficiently close:

$$\left| \Pr[\mathsf{TNT}(T_\ell, X_\ell) = Y_\ell \mid Q_{\ell-1}] - \Pr[\widetilde{\Pi}(T_\ell, X_\ell) = Y_\ell \mid Q_{\ell-1}] \right| \le O\Big(\frac{\ell}{2^{2n}}\Big).$$

*Then by the core lemma of $\chi^2$ method: get the final bound on the indistinguishability: When $D$ makes $q$ queries (including forward and backward ones) to $\mathsf{TNT}^{\pi_1,\pi_2,\pi_3}$ or $\widetilde{\Pi}$, it holds*

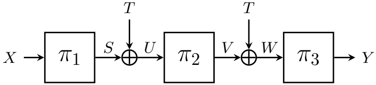
$$\left| \Pr[D^{\mathsf{TNT}^{\pi_1,\pi_2,\pi_3}} = 1] - \Pr[D^{\widetilde{\Pi}} = 1] \right| \le \sqrt{q \times O\Big(\frac{q^2}{2^{2n}}\Big)} = O\Big(\frac{q^{1.5}}{2^n}\Big)$$

# Mode-level Comparison

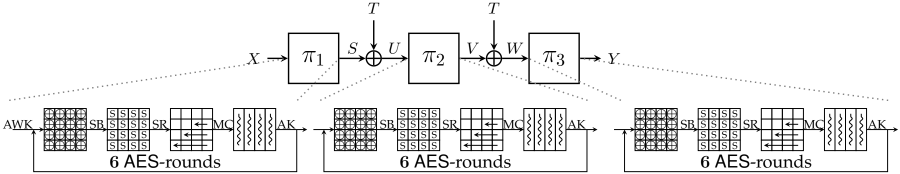
| | #T | #cost | AXU? | tdk | security ($\log_2$) | |
|---|---|---|---|---|---|---|
| LRW1 | $n$ | 2 SPRPs | no | no | $n/2$ | [LRW02] |
| XEX | $n$ | 1 SPRP | yes | no | $n/2$ | [Rog04] |
| LRW2 | * | 1 SPRP | yes | no | $n/2$ | [LRW02] |
| $\mathrm{CLRW2}_2$ | * | 2 SPRPs | yes | no | $3n/4$ | [Men18; JN19] |
| $\mathrm{CLRW2}_r$ | * | $r$ SPRPs | yes | no | $\frac{rn}{r+2}$ | [LS14] |
| Min | $t$ | 2 SPRPs | no | yes | $\max\{n/2, n-t\}$ | [Min09] |
| $\widetilde{F}[1]$ | $n$ | 1 IC | no | yes | $2n/3$ | [Men15] |
| $\widetilde{F}[2]$ | $n$ | 2 ICs | no | yes | $n$ | [Men15] |
| $\widetilde{E1}, \ldots, \widetilde{E32}$ | $n$ | 2 ICs | no | yes | $n$ | [Wan+16] |
| XHX | * | 1 IC | yes | yes | $n$ | [Jha+17] |
| XHX2 | * | 2 ICs | yes | yes | $4n/3$ | [LL18] |
| TNT | $n$ | 3 SPRPs | *no* | no | $2n/3$ | |

# New Approach to Dedicated TBCs

1. The framework TNT: TBC-mode has **BBB security** $2^{2n/3}$



2. AES-based instantiation TNT-AES:



Partially inherited from TNT – the most simple BBB-secure tweaking method & AES – both strong and efficient blockcipher, TNT-AES has

- ⋆ **security with provable and cryptanalysis support** ("prove-then-prune" [HKR15])
- ⋆ **competitive performance in the retweaking scenario**

Thanks for your attention!

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