Integration of False Data Detection with Data Aggregation and Confidential Transmission in Wireless Sensor Networks

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Outline

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Security Vulnerability of Wireless Sensor Networks

- Security attacks
  - False Data Injection (FDI)
    - Compromised nodes (CNs) decrease data integrity.
  - Data Forgery
  - Eavesdropping
- Where FDI by CNs possibly occurs?
  - Data Aggregation (DA)
  - Data Forwarding (DF)
- False data transmission depletes
  - the constrained battery power, and
  - the bandwidth utilisation

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False Data Detection (FDD)

- Conventional work
  - Most discussed FDD during DF.

    Challenge! Any data change between two communicating endpoints is considered as FDI.
- Ozdemir and Cam's approach
  - attempts to correctly determine whether any data alteration is due to DA or FDI.
  - A Data Aggregation and Authentication protocol
    - against up to T CNs
    - over the encrypted data
    - for FDD both by a data aggregator and by a non-aggregating node

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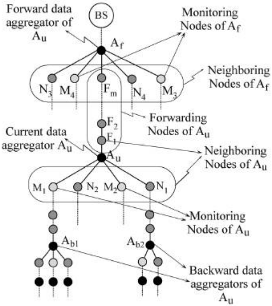
Basic Assumptions

- Network
  - A densely deployed sensor network of certain large size
- Sensor
  - Overlapping sensing ranges
  - Role change
    - Sensor nodes rotatively assumes the role of data aggregator.
  - Limited computation and communication capabilities
- Message
  - Time-stamped
  - Nonce used to prevent reply attacks
- Intrusion ways to compromise nodes
  - Physical capturing
  - Radio communication channel attack

Network Topology

- Data aggregators are chosen in such a way that
  1. there are at least T nodes, called **forwarding nodes**, on the path between any two consecutive data aggregators; and
  2. each data aggregator has at least T neighbouring nodes.



Generation of MACs

- Only data aggregators encrypt and decrypt the aggregated data.
- The forwarding nodes first verify data integrity using MACs and then relay the data if it is not false.
  - Two Full-size MACs (FMACs), each of which consisting of $T + 1$ subMACs, for a pair of plain and encrypted data
    - One computed by a data aggregator
    - T subMACs generated by its T monitoring nodes
  - The same Pseudo-Random Number Generator (PRNG), termed f
    - Random numbers between 1 and 32

Generation of MACs

- subMAC generation of data D by neighbouring node N_i of data aggregator A_u for its pairmate F_j
  1. Establish the shared key $K_{i,j}$ between N_i and F_j.
  2. Compute MAC(D) using $K_{i,j}$.
  3. Assuming that S denotes the size of MAC(D) in bits, selects $S/(T+1)$ bits to form subMAC(D) using its PRNG and $K_{i,j}$ as the seed.
- subMAC verification of D by F_j for its pairmate N_i
  1. Compute the MAC(D).
  2. Run its PRNG $S/(T+1)$ times to generate subMAC(D) with $K_{i,j}$ as the seed.
  3. Compare two subMAC(D)'s.
- PRNG synchronisation achieved by packet sequence numbers

Key Establishment

- Pairwise key establishment
  - Sybil attacks
    - A compromised node fakes multiple identities to establish pair relations with more than one monitoring nodes.
  - To prevent from Sybil attacks, a monitoring node can share a pairwise key with another node in multiple hops.
- Group key establishment
  - Group key K^u_{group} for data aggregator A_u and its neighbouring nodes is used to select the monitoring nodes and to protect data confidentiality while data transmitting.

Limitations

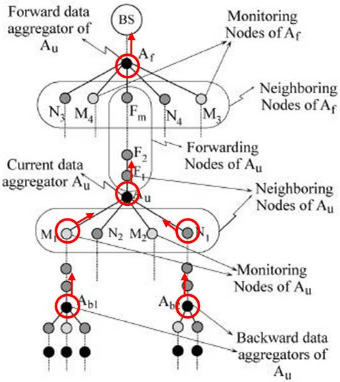
- The value of T depends strictly on several factors, such as geographical area conditions, modes of deployment, and so on.
- The pairwise key establishment between non-neighbouring nodes takes more time than that between direct neighbouring nodes.
- Compromising only one legitimate group member discloses not only some or all of the past group keys but also the current group key.

Outline

Notations used in DAA

TABLE I
SUMMARY OF NOTATIONS

Notation	Explanation
A_u	Current data aggregator.
A_f	Forward data aggregator.
A_b	Backward data aggregator.
BS	Base Station.
N_i	Neighboring node i of A_u or A_f.
F_j	Forwarding node j of A_u.
M_k	Monitoring node k of A_u.
K^u_{group}	Group key of A_u and its neighbors.
$K_{i,j}$	Shared key between sensor nodes i and j.
$E_{K_{ij}}(D)$	Encryption of data D with key K_{ij}.
$MAC_{K_{ij}}(D)$	Message Authentication Code of data D calculated with key K_{ij}.



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Algorithm MNS (Monitoring Node Selection)

Table: Choose T monitoring nodes from n neighbouring nodes of A_u

1.	$A_u \Rightarrow$ all nodes	request two random numbers with node ID
2.	$N_i \rightarrow A_u$	R_a and R_b generated by $f(K_{u,i})$ $\text{MAC}_{K_{u,i}}(R_a \mid R_b)$
3.	$A_u \Rightarrow$ all nodes	$\{N_1, \ldots, N_n\}$ in the receiving order $\{R_1, \ldots, R_{2n}\}$ labeled in an ascending order $\text{MAC}_{K^u_{group}}(R_1 \mid \cdots \mid R_{2n})$
4-1.	$N_i \rightarrow A_u$	(**verified**)$E_{K_{u,i}}(\text{MAC}_{K^u_{group}}(R_1 \mid \cdots \mid R_{2n}))$
4-2.	$N_i \rightarrow A_u, N_j$'s	(**unverified**)restart from 1.
5.	N_i	for $1 \leq k \leq T$, compute $I_k = [(\sum_{j=k}^{n-1+k} R_j + K^u_{group}) mod(n)] + 1$ to determine T monitoring node ID's of A_u

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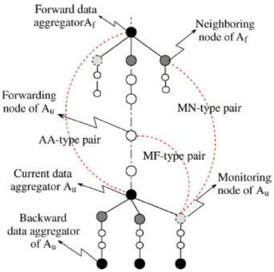
Three Types of Node Pairs

- $2T + 1$ node pairs are formed.
  AA-type pair One pair between A_u and A_f
  MF-type pair T pairs between M_k of A_u and F_j towards A_f
  MN-type pair T pairs between M_k of A_u and N_i of A_f
- T M_k's selected in Step 1 distinctly choose their own pairmates to form MF-type and MN-type pairs.



Pairmate Selection

1.	$A_f \rightarrow F_j \rightarrow A_u$	pairmate discovery message N_i's of A_f $\mathrm{MAC}_{K_{f,u}}(N_i\text{'s})$ F_j's IDs for $1 \leq j \leq h$
2.	$A_u \Rightarrow T\ M_k$'s	$\mathrm{MAC}_{K^u_{group}}(F_1 \mid \cdots \mid F_h)$ for new, random forwarding node labeling $\mathrm{MAC}_{K^u_{group}}(N_i\text{'s})$s
3.	$M_k \rightarrow A_u$	one forwarding node one neighbouring node
4.	$A_u \Rightarrow T\ M_k$'s	two pairmate lists of size T
5.	M_k	pairmate verification

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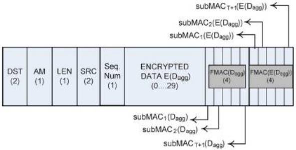
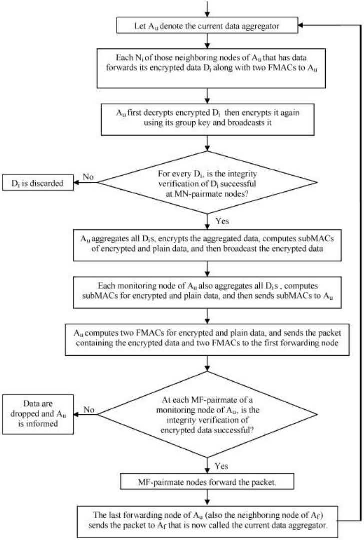
Data Confidentiality

- One pairmate computes a subMAC, and the other pairmate verifies the subMAC.
- subMACs for plain data are used for FDD during DA.
- subMACs for encrypted data are used for FDD during DF.
- Each data aggregator forms two FMACs as the following figure.



- A_u determines the order of subMACs and informs each forwarding node about its subMAC location individually.
  - probability of FDI at a forwarding node $= (1/2)^{32}$

Algorithm SDFC



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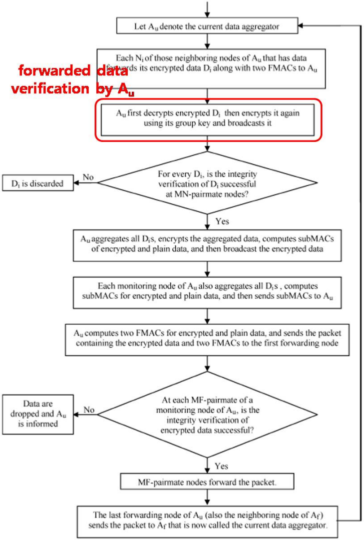

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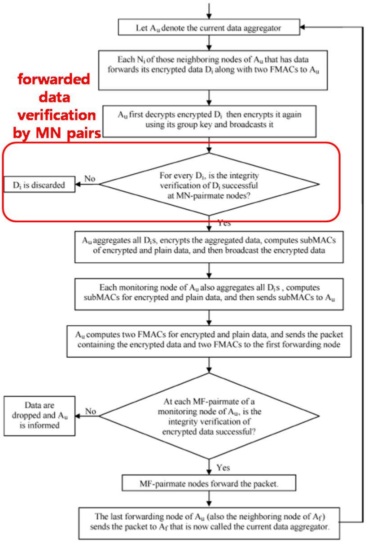

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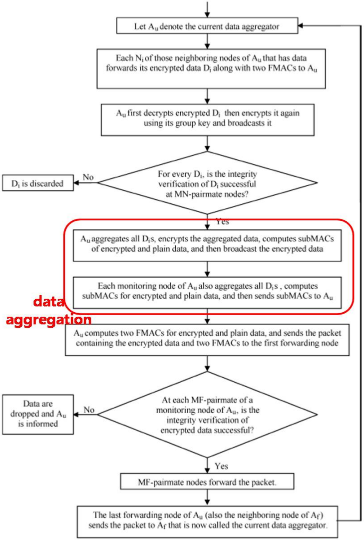

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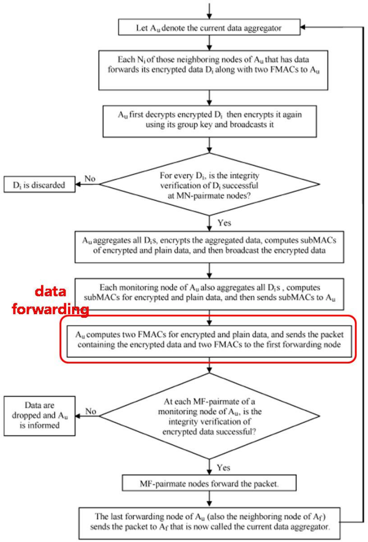

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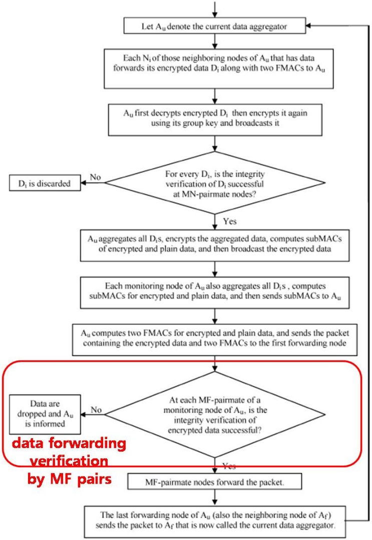

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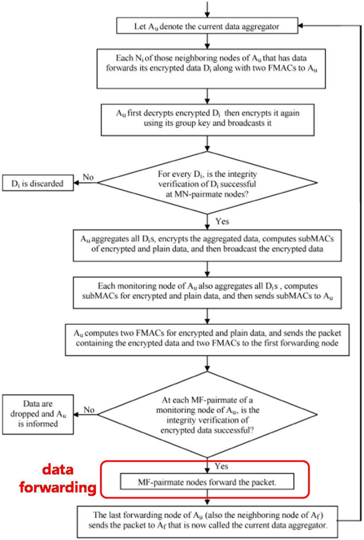

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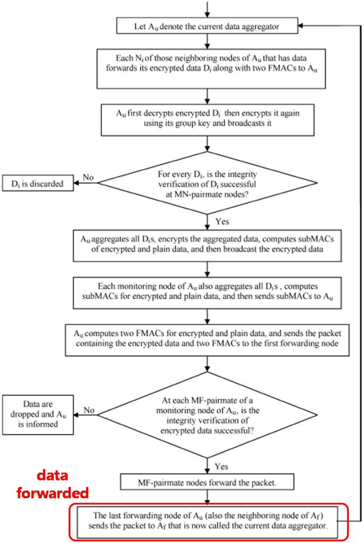

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Security Analysis of Algorithm SDFC

Lemma 1

Assuming that A_u is compromised and there are additional at most $T-1$ collaborating compromised nodes among the neighbouring nodes of A_u and A_f, any false data injected by A_u are detected by the A_f's neighbouring nodes only in SDFC.

- *Data verification by the monitoring nodes of A_u and the neighbouring nodes of A_f*

Lemma 2

Assuming that A_u and A_f are not compromised, any false data injected by any subset of A_u's forwarding nodes are detected by A_f in SDFC.

- *Data verification by A_f*

Security Analysis of FMAC and subMAC

- Changing the size of MAC
  - Security Level vs. Communication Overhead
- Probability of FDI at a node $= (1/2)^{32}$ for 4-byte FMACs
  - Probability of FDI into a subMAC $= (1/2)^{32/(T+1)}$
  - The size of FMAC $= T + 1$

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Computational Cost of Algorithm SDFC

Computation	Traditional Work	SDFC
MAC	1	$4(T+1)$ $= (T+1)$ subMACs $\times$ 2 FMACs $\times$ a pair
Aggregation	1	$T+1$ $=$ 1 by aggregator $+$ T by monitors
Encryption/ Decryption	1	$T+2$ $=$ 1 encryption by A_u $+$ T decryptions by monitors $+$ 1 decryption by A_f

- Only the first MAC computation consumes much resource.
- Data transmission requires much more energy than data computing in wireless sensor networks.

Communication Cost of Algorithm SDFC

D_{ADD}	the amount (in bytes) of data transmission using ADD of two FMACs
$D_{tradAuth}$	the amount (in bytes) of data transmission using the traditional scheme of a MAC
L_{tos}	the length (in bytes) of an authenticated and encrypted data packet
α	the number of data packets generated by legitimate nodes
β	the number of false data packets injected by up to T compromised nodes
H_d	the average number of hops between two consecutive data aggregators
H	the average number of hops that a data packet travels in the network

$$D_{ADD} = (L_{tos}+4)(\alpha H + \beta H_d) + T(L_{tos}+4)(\alpha+\beta) + \frac{4T}{T+1}(\alpha+\beta)$$

$$D_{tradAuth} = L_{tos} H(\alpha+\beta)$$

- data transmission by a data aggregator
- data transmission by T monitors
- subMACs transmission by T monitors

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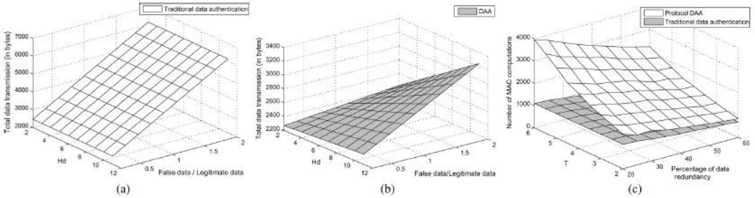
Cost Comparison

- $L_{tos} = 41, H = 50, H_d \leq 12$ and $\beta/\alpha \geq 0.2$



- Comparing (a) and (b), D_{ADD} more mildly increases than $D_{tradAuth}$.
- (c) shows that the value of T trades off between security and computation overhead in the network.
- (c) also illustrates the impact of data aggregation.

Outline

Contributions and Future Work

- Contributions
  - False data detection during data aggregation
  - Integration of data confidentiality and false data detection
  - Less communication overhead (by fixing the size of each FMAC)
- Future work
  - Security and efficiency improvement in networks where every sensor enables data forwarding and aggregation at the same time