# A MAC Protocol for Ad-Hoc Underwater Acoustic Sensor Networks

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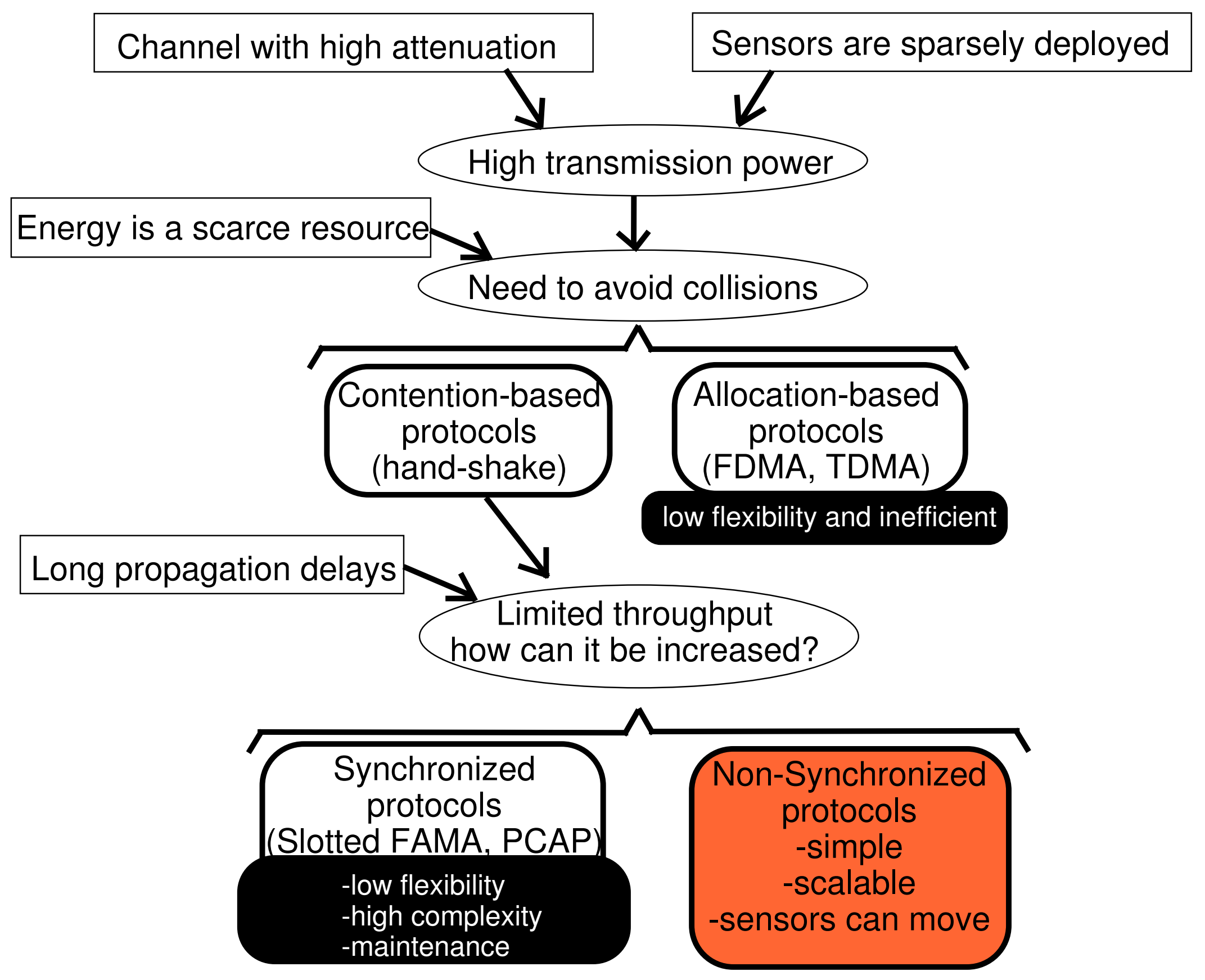
## Problem



Channel with high attenuation

Sensors are sparsely deployed

High transmission power

Energy is a scarce resource

Need to avoid collisions

Contention-based protocols (hand-shake)

Allocation-based protocols (FDMA, TDMA)

low flexibility and inefficient

Long propagation delays

Limited throughput how can it be increased?

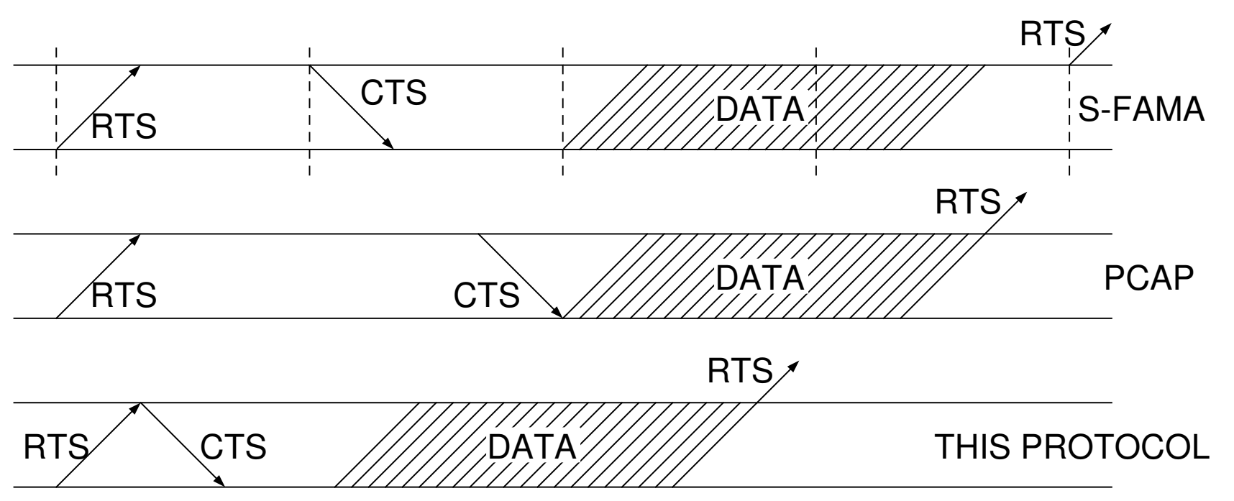
Synchronized protocols (Slotted FAMA, PCAP)

-low flexibility
-high complexity
-maintenance

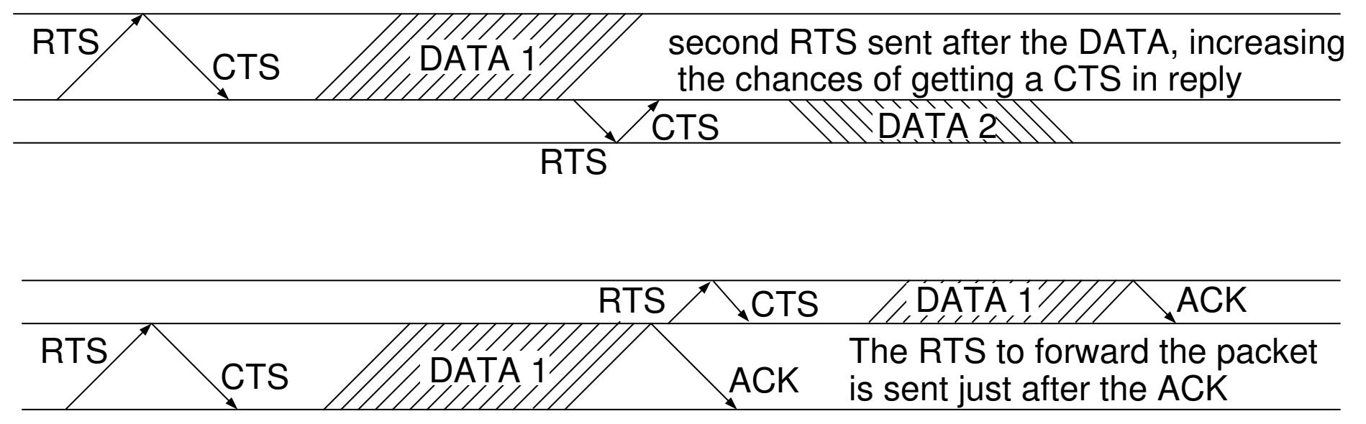
Non-Synchronized protocols
-simple
-scalable
-sensors can move

## Protocol Highlights

- **High throughput:** The throughput is increased by exploiting the receiver's tolerance to interference to make hand-shakes between close nodes much shorter in exchange for slightly lengthening those between far ones. The fact that they are asynchronous also helps.



- **No need for synchronization:** It makes the protocol simpler and saves the power otherwise needed for periodic maintenance.
- **Short end to end delays:** As it is asynchronous, nodes can concatenate transmissions sending several packets once they gain the channel. If acknowledges are used, the receiver can forward the incoming packet nearly right away without need for contention.



- **Adjustable to each network:** For a network in which most links are close to the transmission range, $t_{min}$ needs to be nearly as long as the round-trip time corresponding to the maximal range. When some links are shorter, it can be reduced.
- **Scalable, flexible and stable:** Nodes can get in and out of the network easily, can move and the contention ensures a certain throughput even with very high loads.

## Abstract

A medium access control (MAC) protocol is proposed that is suitable for non-synchronized ad-hoc networks, and in particular for the energy-constrained underwater acoustic networks which are characterized by long propagation delays. The protocol exploits the difference in the link lengths between the nodes instead of using waiting times proportional to the maximal link length. To do so, it relies on a receiver's ability to tolerate a certain level of interference. By minimizing the length of the hand-shake procedure preceeding the data transmission, the throughput efficiency is increased as compared to the previously proposed protocols, while collision avoidance minimizes the energy consumption.

## Protocol description

The protocol is specified as follows. Upon receiving an RTS, a receiver immediately replies with a CTS, then listens to the channel waiting for the data packet. If during this listening period it hears an RTS meant for some other node, it sends a very short warning packet to its partner (the node to whom it had sent the CTS).

Upon receiving a CTS, a node waits some time before transmitting the data packet. If it hears another CTS or a warning from its partner during this time, the node aborts transmission. The length of the waiting period will depend upon three parameters:

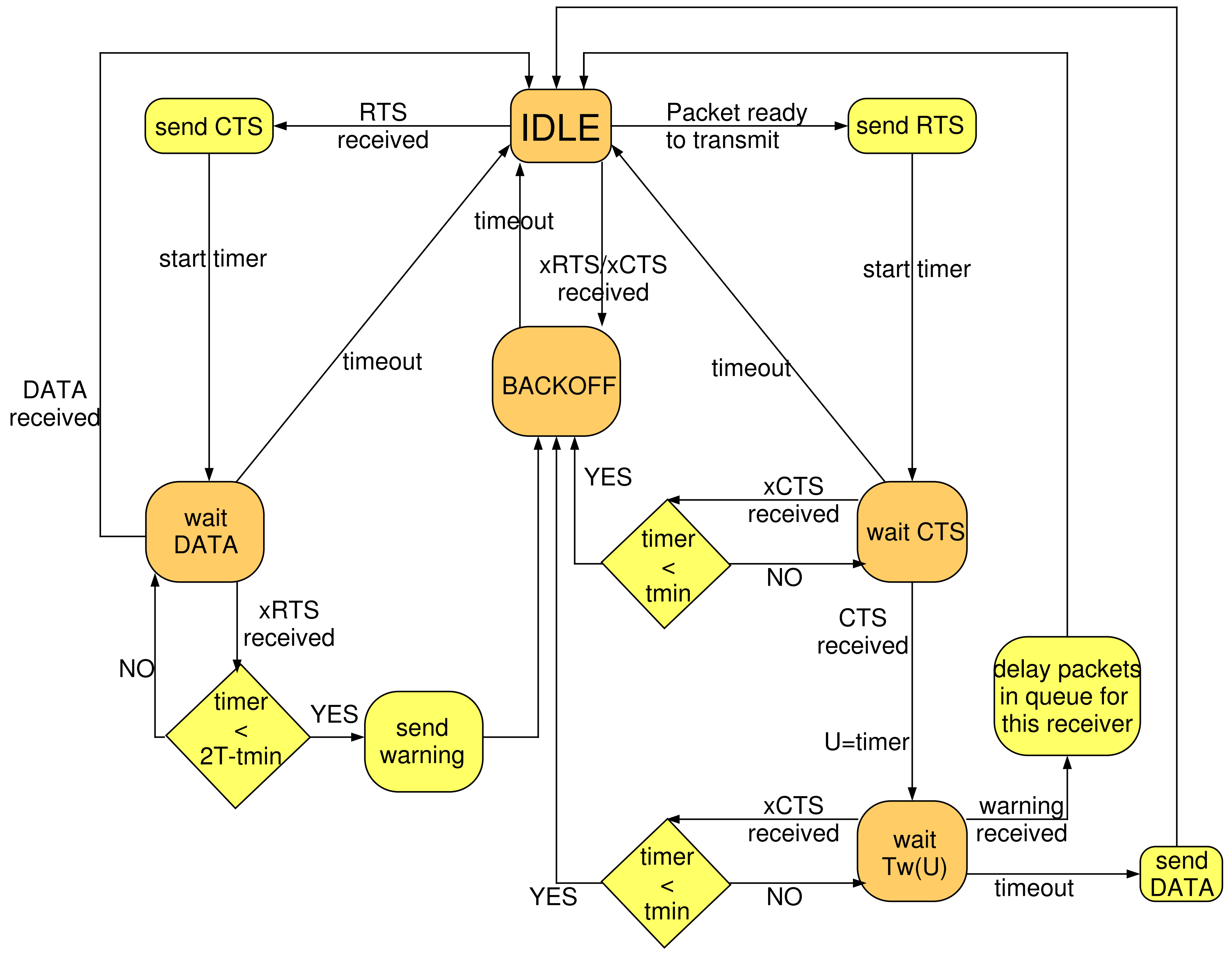
- **Distance between the nodes (U)**, which the sender can learn by measuring the RTS/CTS round-trip time
- **Receiver's tolerance to interference (D)**, being U+D the minimal distance to an interfering node for which correct reception is still possible
- **Pre-fixed minimum hand-shake length** ($t_{min}$), to optimize the protocol for a given network

Denoting by $c$, the speed of sound underwater and by $t_{data}$ the duration of a data packet, the waiting period is determined from:

$$T_w = \begin{cases} t_{min} - 2U/c, & U/c < t_1 \\ 2(U+D)/c - t_{min}, & U/c \in (t_1, t_2) \\ 2D/c + t_{data}, & U/c > t_2 \end{cases} \qquad where \qquad \begin{array}{l} t_1 = \frac{t_{min} - \min(D/c, t_{data})}{2} \\ t_2 = \frac{t_{data} + t_{min}}{2} \end{array}$$

The additional restriction that $T_w > 2D/c$ avoids collisions with control packets.

Hand-shakes between close nodes can be made shorter because the propagation delay between them is shorter and they only need to avoid collisions from a few other nodes. On the other hand, handshakes between far nodes become longer but a trade-off can be achieved by means of $t_{min}$.



send CTS

RTS received

IDLE

Packet ready to transmit

send RTS

start timer

timeout

xRTS/xCTS received

start timer

DATA received

timeout

BACKOFF

timeout

YES

xCTS received

wait DATA

timer < tmin

NO

wait CTS

xRTS received

CTS received

NO

timer < 2T-tmin

YES

send warning

delay packets in queue for this receiver

U=timer

xCTS received

warning received

wait Tw(U)

send DATA

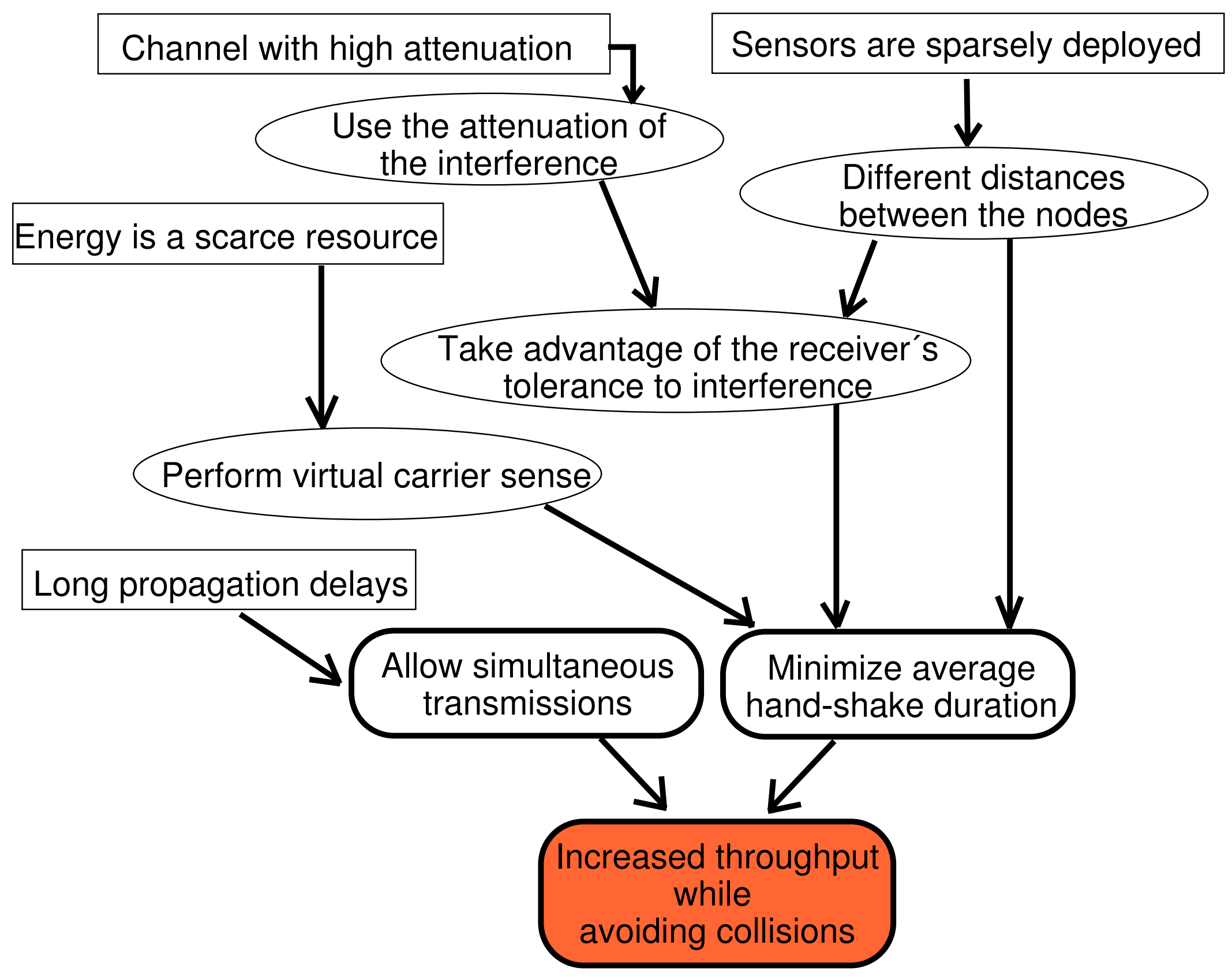
timer < tmin

YES

NO

timeout

## Solution



Channel with high attenuation

Sensors are sparsely deployed

Use the attenuation of the interference

Different distances between the nodes

Energy is a scarce resource

Take advantage of the receiver´s tolerance to interference

Perform virtual carrier sense

Long propagation delays

Allow simultaneous transmissions

Minimize average hand-shake duration

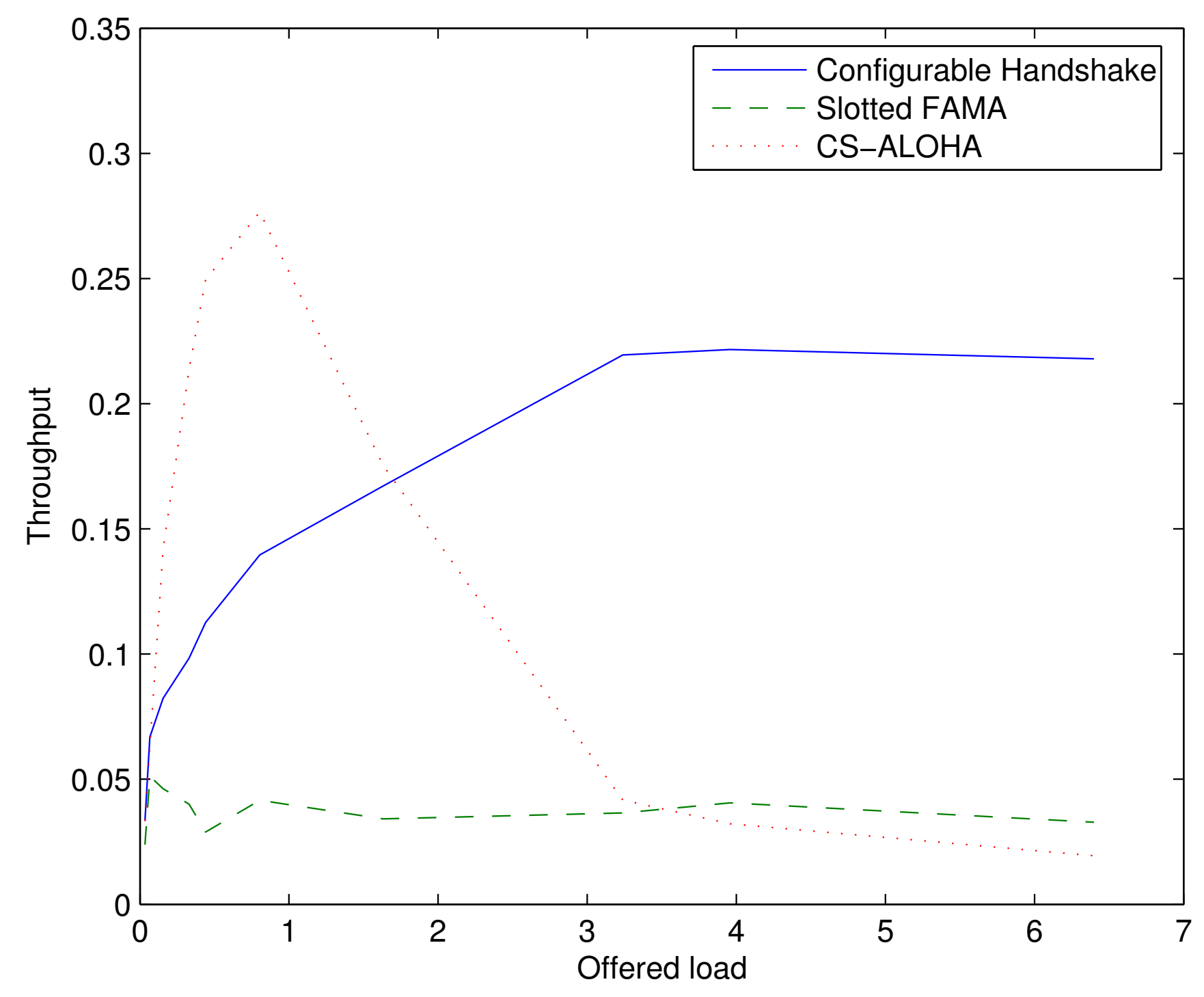
Increased throughput while avoiding collisions

## Simulation Results

**Scenario:** 5x5 km area, divided into 16 squares with a node at a random location within each. Nodes generate packets for random destinations according to a Poisson distribution, and have an infinite transmit queue. The Transmission range is 7 km, so that every node can hear each other. Noiseless channel is assumed.

**Parameters:** Assuming that nodes require 20 dB of SIR for correct reception and a carrier frequency of 35 kHz, we obtain according to Thorp, that ***D*=1.75 km**. RTS and CTS are 48 bits long, warnings 24 bits long, and data packets have 9600 bits. The transmission rate is 4800 bits per second. We used $\boldsymbol{t_{min} = T}$, half the round-trip time.

**Other protocols:** CS-ALOHA: nodes transmit their packets whenever they see the channel idle. Slotted FAMA: nodes are synchronized and packets can only be sent at the beginning of a slot (T seconds long). No acknowledges were used in either of them.



The achieved throughput is several times higher than the one with slotted FAMA. CS-ALOHA is faster initially, but degrades as the load increases and always wastes too much energy on collisions. Power efficiency is similar in our protocol and Slotted FAMA, over 95% for the present simulation scenario.