A Control Plane For Prioritized Real-Time Communications In Wireless Token Ring Networks

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Outline

- Real-time Communications
  - Basics
  - Wireless aspects & challenges
- Token Ring Protocols For Wireless Networks (Survey)
  - WTRP, iWTRP, EWTRP, WDTP …
- System Architecture
  - Timed Token MAC Protocol & SBA
- Proposed Control Plane
  - FSM & Use cases
- Simulations
- Conclusions
- Future Work

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Research Overview

- A centralized control plane incorporating the timed token protocol in the MAC layer for providing hard real-time guarantees in wireless token ring networks
  - Admission control
  - Station eviction
  - Traffic differentiation
- High priority stations have more chance of admittance and stations with low priority can be removed from the ring
- *Dynamic Ring*

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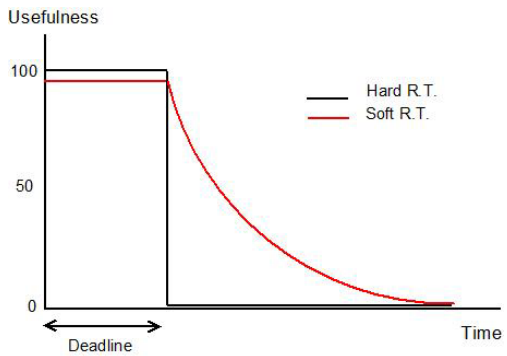
Real-time Communications

- Both logically and temporally correct systems
- Hard vs. soft real time systems



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Desirable Properties for Real-time Communications

- Low jitter
- Low and predictable latency
- Easy to integrate heterogeneous traffic
- Adaptable to dynamically changing network and traffic conditions
- Scalable
- Low processing overhead per packet

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Real-time Communications in Wireless Networks

- Higher BER (bit error rate) than wired links
  - Usually not the first choice for real-time systems
- Should be addressed in the MAC and physical layers in wireless networks
- Most research is done in the MAC layer
  - 802.11 (WiFi)

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Real-time Communications in Wireless Networks

- Our focus is on the token ring networks
  - Ring topology
  - A token is circulating
  - Receive token
    - If data pending send it and then pass the token
    - If no data just pass the token

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Why Token Ring ?

- The upper bound of the latency in these networks is predictable
  - the time that a station can hold the token is known, then a station in the ring can predict the worst case arrival time of the next token
- No collision
  - So e2e delay is lower than collision protocols
- Fairness

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Token Ring Protocols For Wireless Networks

- Many token ring protocols have been proposed for wireless networks
- Most of them are based on WTRP

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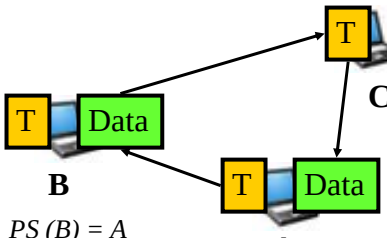
Wireless Token Ring Protocol



- The ring adapts dynamically to configuration changes
- Gives all stations regular on-time access with a fair share of the bandwidth
- Completely distributed: No super administrator
- IEEE 802.11 compliant implementation
  - Different network built on hardware in the market

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Wireless Token Ring Protocol

- "WTRP (Wireless Token Ring Protocol) is a medium-access-control (MAC) protocol for applications running on wireless ad-hoc networks that provide quality of service."
- WTRP provides QoS guarantees in terms of bounded latency and reserved bandwidth which are both crucial for real-time applications
- WTRP is a distributed protocol which supports dynamic network topologies
  - Join & leave

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iWTRP

- IWTRP provides a novel method to allow multiple tokens and as a result it allows simultaneous transmissions (spatial reuse)
- Designed for wireless metropolitan area networks (WMANs)
- Two assumptions
  - each station in the ring has two radio interfaces one of which is for clockwise and the other is counterclockwise transmission used for transmitting in both directions of the ring since there can be multiple tokens
  - the stations are not mobile

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iWTRP

- IWTRP uses a token re-generation idea to generate multiple tokens
- Can cause more collisions in the network
- (RTS/CTS) handshaking and the network allocation vector (NAV) technique used
- Hybrid solution based on WTRP and 802.11
- As a result of adopting the spatial reuse and the token re-generation idea, iWTRP enhances the total throughput of the network

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Wireless Dynamic Token Protocol (WDTP)

- A MAC protocol for mobile adhoc networks (MANET) which is actually based on WTRP
- "In WDTP, the token dynamic transfer algorithm, which is similar to the traversal of graph by depth first search, is proposed to substitute the method of token transfer in WTRP to control the token transfer. With this proposed algorithm, the path that the token passing through can be adjusted automatically corresponding to the subnet's dynamic topology and has not to be a ring."

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WDTP

- Stations are clustered in the network as subnets and transmitting on different channels
- These subnets correspond to the logical token rings in WTRP
  - In each subnet there is an owner which is responsible for token maintenance
- In order to determine its successor a station uses the network topology information and some history that their neighbor stations held the token

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WDTP

- Each station maintains a TPQ
- The token is passed to the *head* of the TPQ
- The stations that do not have the token listen to the channel.
  - If they discover that any station has processed the token transfer then they push this station to the rear of their TPQs. And if this node is already present in TPQ then this record is removed from the TPQ
- The head of the TPQ is actually the station which has not hold the token for longest time. The order of token passing is the order of the nodes in the TPQ

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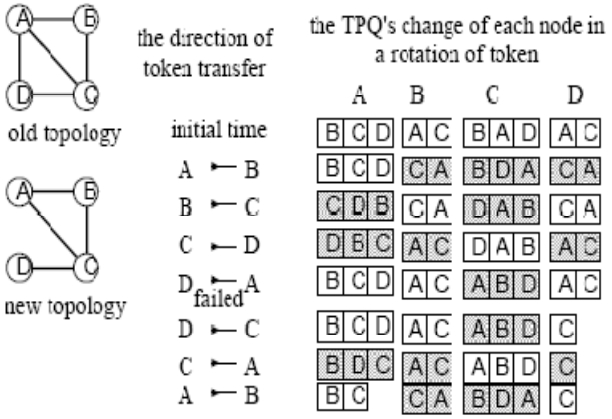
WDTP



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WDTP

- By the proposed algorithms, the WDTP increases the channel efficiency and the token path maintenance is simplified
- As a result WDTP improves the adaptability to network topology and increases the throughput

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Rether

- Rether is a QoS mechanism that provides bandwidth guarantees to individual flows over 802.11 networks. Rether does not make any changes to the MAC layer. It is implemented on top of the data link layer and below the network layer
- Client-server architecture
  - The Wireless Rether Server (WRS) is responsible for admission control and coordination
  - A centralized token passing method in which a center is responsible for token passing and maintenance

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Rether

- Implicit bandwidth reservation approach
- Supports mobility
- Centralized system
- Traffic differentiation

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A Token Based MAC Protocol for Wireless Industrial Control Networks

- WICN is a single hop adhoc network with the following properties
  - Frame lengths are shorter.
  - The network has a small radius and so mobility is limited in a small region.
  - The network should be integrated with upper layers in the intranet
- The protocol should provide QoS guarantees in terms of bounded delay and high reliability
- Minor modifications to WTRP (for power and reliab.)
- As a result it performs better than CSMA/CA in terms of end to end delay and throughput

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High Frequency Token Protocol (HFTP)

- HFTP is based on WTRP but supports two new operations one of which is token relaying and the other is ring merging
- "…quickly recovers from common token loss and duplication scenarios, and that deals efficiently with changes in network connectivity and membership …"

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HFTP

- The token relay mechanism is used whenever there is a problem in the wireless link between two stations
- The ring merging operation can be used for partitioned networks which regains its connectivity

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Enhanced Wireless Token Ring Protocol (EWTRP)

- It introduces three mechanisms into WTRP which are the preemption mechanism, hibernation mechanism and contention mechanism
- Preemption Mechanism: EWTRP dynamically adjusts this THT value according to the network load possibly at each cycle

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Enhanced Wireless Token Ring Protocol (EWTRP)

- Hibernation Mechanism: When a station estimates that its buffers will be empty for some time then this station notifies its predecessor how long it will hibernate
- Contention Mechanism: EWTRP introduces contention periods to WTRP. A station using EWTRP may choose not to join to a network if the traffic load of the station is relatively low; they just contend for the channel in the contention periods

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A Token Passing MAC Protocol for Ad Hoc Networks (T-MAH)

- T-MAH is a distributed MAC protocol for multi-hop networks
- Stations are organized in clusters with each cluster having a leader
- Clusters are also called token groups in T-MAH
  - Clustering stations reduce the number of collisions
  - Network resources are utilized more effectively

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But …

- Lack of a control plane
  - Management is the key to steer the behaviour of the systems
- Focus is only on the MAC sublayer
  - Probably enhancing WTRP
- Hard real-time is not a concern

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System Architecture

- Timed token protocol in the MAC layer
  - Able to provide hard real-time communications capabilities because of its special timing properties
  - The upper bound for the delay is known (2.TTRT) and hence the system becomes predictable which is the primary requirement for real-time systems

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System Architecture

- Messages generated in the network are classified as synchronous and asynchronous messages
- There are *n* streams of synchronous messages at a certain moment $S=\{S_1, S_2, S_3,..., S_n\}$, with stream S_i originating at node *i*

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System Architecture

- $S_i=(C_i , P_i , D_i, T_i)$
- C_i is the maximum amount of time required to transmit a message in the stream
- P_i is the period of messages in the stream
- D_i is the relative deadline of messages in the stream, that is, the maximum amount of time that can elapse between a message arrival and completion of its transmission
- T_i is the traffic class (priority) of the stream

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System Architecture

- Each synchronous message stream places a certain load on the system
- The effective utilization of a stream :

$$U_i = \frac{C_i}{\min(P_i, D_i)}$$

- The total utilization of the synchronous message set S is the fraction of time the network is used to transmit the synchronous messages and denoted as U(S)

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System Architecture

- Stations negotiate TTRT at initialization
- Each station is assigned a H_i
  - Fraction of TTRT value and determines the maximum time a station is allowed to transmit its synchronous messages every time it receives the token
- Challenging research problem

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Timed Token Protocol Main Idea

- Synchronous messages are transmitted without exceeding the H_i value
- After transmitting the synchronous messages, if there is some time left the asynchronous messages are also transmitted

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Synchronous Bandwidth Allocation

- Many algorithms are proposed
- Zhang and Lee examines three SBA schemes namely the NPA (Normalized Proportional Allocation), MCA (Minimum Capacity Allocation) and EMCA (Enhanced Minimum Capacity Allocation) and show with numerical examples that none of these schemes are optimal
- EMCA is used in our research

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Proposed Control Plane

- A management station in the network that has the knowledge of global state
  - Possible to make better decisions
  - Ease of management
- This makes the system a *centralized* system
  - Scalability ? No
    - The system is actually designed for *small scaled* wireless local area networks
  - SPOF ?
    - Possible but in controlled networks generally a super administrator exists

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Proposed Control Plane

- Stations in the network send connection requests to the management station to join the ring
- Connections have fixed lifetimes
- After a connection is set up, a connection id is generated by the MAC layer and returned to the upper layer which is used to tear down the connection later on

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Proposed Control Plane

- A connection request consists of the following parameters
  - C_i , P_i, D_i, TC_i, SA, DA

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Proposed Control Plane

- Following traffic classes are defined the system which are defined by IEEE 802.11e standard
  - Voice
  - Video
  - Best effort
  - Background

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Proposed Control Plane

- Three important functions
  - Admission control procedure
  - Station eviction procedure
  - Traffic differentiation mechanism

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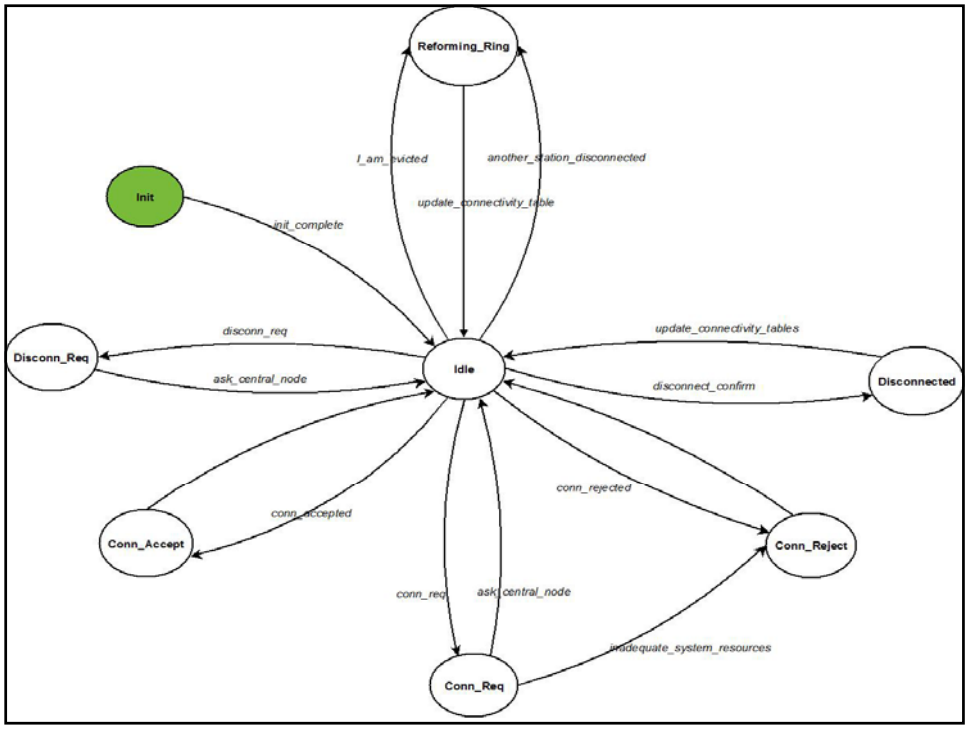
Algorithm: Dynamic Ring Management Algorithm

```
procedure DRM(Connection_Request[Sp])
p:Source, q:Destination, Ti: Traffic Class of Si
begin
  satisfied = EMCA(S+Sp,TTRT,τ,H);
  if satisfied then
   broadcast(H,TTRT);
   return ACCEPT;
  end if
  staToRemove = NULL;
  for ∀si ∈ S
   if q != i AND Ti < Tp then
    OK = EMCA(S+Sp-Si,TTRT,τ,H);
    if OK then
      if staToRemove = NULL
         OR TstaToRemove > Ti then
         staToRemove = i;
  end for
  if staToRemove != NULL then
   broadcast(staToRemove,H,TTRT);
   return ACCEPT;
  end if
  return REJECT;
end
```



Sample Use Cases for the Control Plane

- Wireless Industrial Automation Networks
- Small Scaled Military Networks
  - The carried data is a vital control or monitoring information
  - Much of the status or control information is carried in short bursts which generally require relatively little bandwidth and connection speed and also the traffic is usually periodic
  - The key point for communication in these networks is the timely delivery without failure

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Simulations

- DES with C++
- Connection requests are generated according to the Poisson probability distribution
- P, C and D are set according to the traffic that will be carried by the connection
- TTRT is 85 ms and τ is assumed as 0
- Nearly same number of connections for each of the traffic classes (377 conns.)

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Simulations

Traffic Class	P=D (ms)	C (ms)
BG	350	30
BE	350	30
VIDEO	350	30
VOICE	350	30

Traffic Class	P=D (ms)	C (ms)
BG	500	25
BE	430	15
VIDEO	250	14
VOICE	150	7

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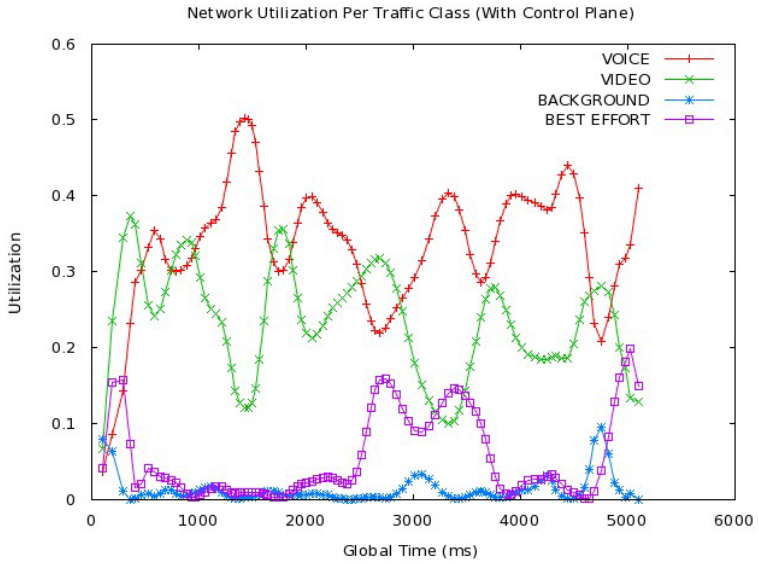
Results

Traffic Class	Total # Of Connection Requests	Accepted	Accepted By Eviction	Rejected	# Of Stations Evicted	Average % of Connection Lifetime Used	% Accepted	% Rejected
BG	90	31	0	59	32	11.33	34.44	65.56
BE	94	44	9	50	36	38.08	46.81	53.19
VIDEO	98	66	27	32	20	91.79	67.35	32.65
VOICE	95	95	52	0	0	100	100	0

Traffic Class	Total # Of Connection Requests	Accepted	Rejected	% Accepted	% Rejected
BG	95	23	72	24.21	75.79
BE	98	33	65	33.67	66.33
VIDEO	94	12	82	12.77	87.23
VOICE	90	14	76	15.56	84.44

Results



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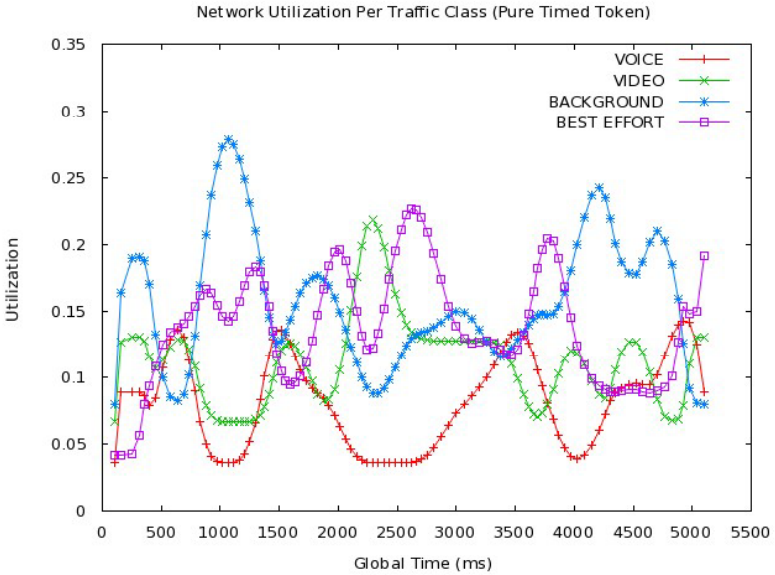
Results



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Results

Traffic Class	Total # Of Connection Requests	Accepted	Accepted By Eviction	Rejected	# Of Stations Evicted	Average % of Connection Lifetime Used	% Accepted	% Rejected
BG	95	36	0	59	37	19.41	37.90	62.10
BE	95	42	13	53	38	39.42	44.21	55.79
VIDEO	95	68	37	27	29	88.09	71.58	28.42
VOICE	92	92	54	0	0	100	100	0

Traffic Class	Total # Of Connection Requests	Accepted	Rejected	% Accepted	% Rejected
BG	95	16	79	16.84	83.16
BE	93	16	77	17.20	82.80
VIDEO	96	15	81	15.62	84.38
VOICE	93	17	76	18.28	81.72

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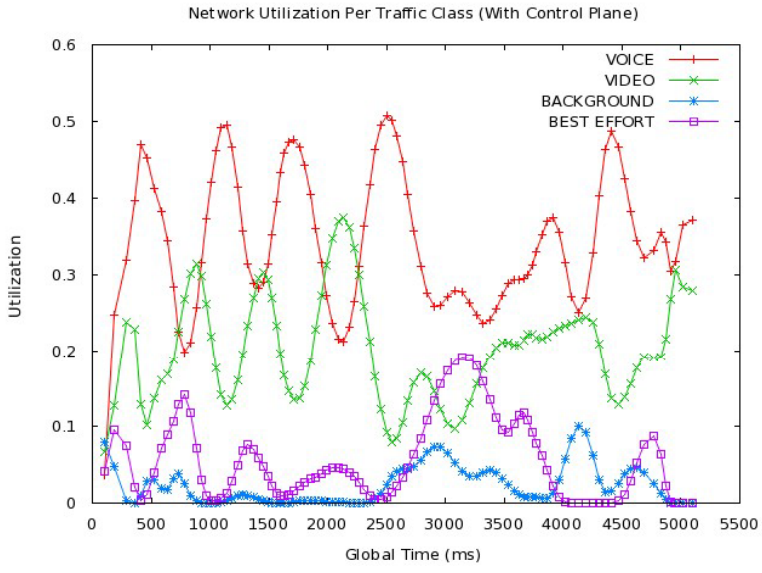
Results



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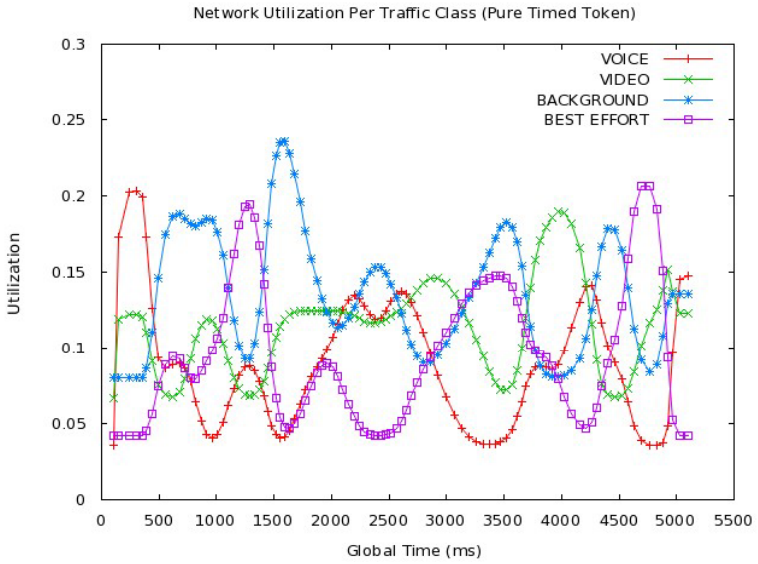
Results



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Conclusions

- The proposed control plane ensures higher priority traffic more bandwidth than lower priority traffic and guarantees that deadline constraints of hard real-time traffic are satisfied
- The wireless token ring network becomes more responsive to the connection requests carrying high priority traffic
- A dynamic ring structure is built
- Throughput of higher priority traffic increases in the network
- The wireless token ring network becomes more suitable for real-time communications

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Future Work

- The proposed control plane utilizing the timed token protocol is a new research topic targeting wireless token ring networks
- So the proposed system can be improved in various ways
- To make the system more scalable the proposed algorithms can be made decentralized
- Another problem that is not addressed in this thesis is the mobility problem and multi-ring problem

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Future Work

- WSNs (Wireless Sensor Network) and Wireless Multimedia Sensor Networks (WMSN) are being deployed for various applications like habitat monitoring, object tracking, nuclear reactor controlling, fire detection and traffic monitoring
- It is an open problem to make the proposed control plane more suitable for wireless multimedia sensor networks
- Decentralized and power aware

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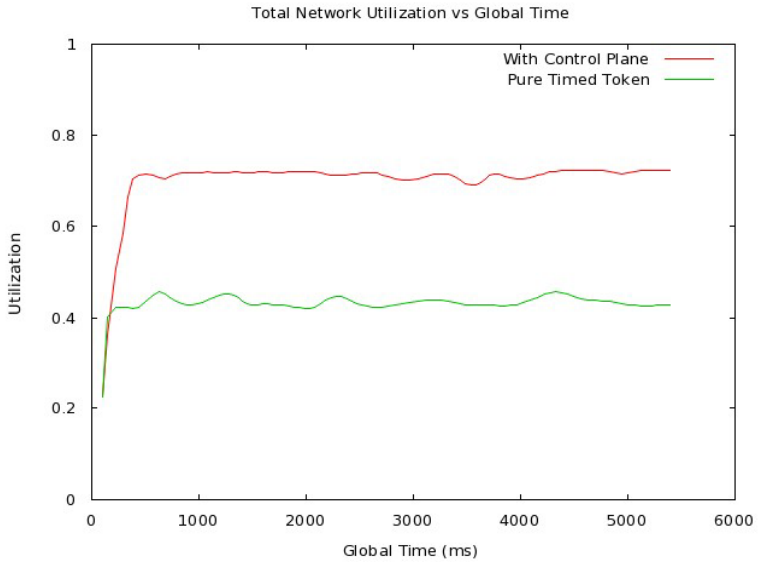
Total Utilization

(P,C,D fixed)



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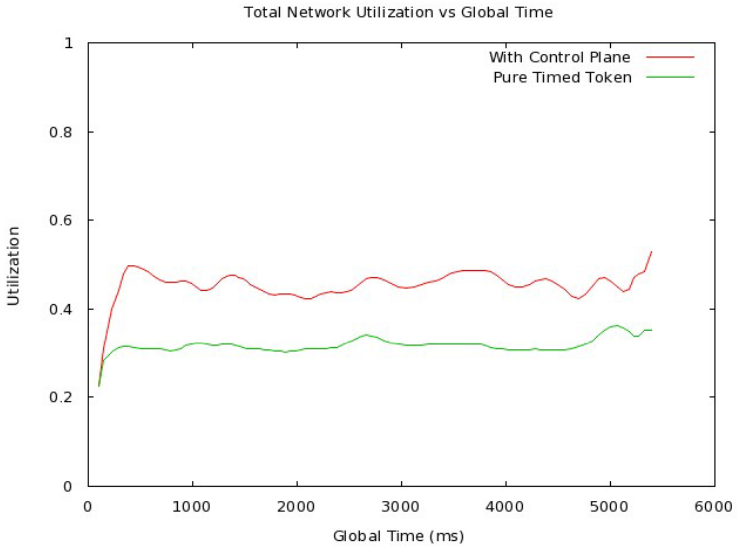
Total Utilization

(P,C,D variable)



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