Transport Layer Design for Named Data Wireless Networking

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***Abstract*—The Named Data Networking (NDN) project is emerging as one of the most promising information-centric future Internet architectures. So far, NDN performance in wireless networks has been largely unexplored, especially for what concerns transport mechanisms, which are crucial to ensure reliable and efficient data delivery while accounting for available resources and network dynamics. In this paper, we propose a transport scheme that effects *self-regulating Interest rate control* (SIRC), reduces the content completion time and more efficiently utilizes channel resources in a wireless ad hoc domain. The presented strategy provides a reliable service that pairs better than most other proposals so far, with the NDN's content multi-homing semantics. A comprehensive evaluation with different traffic loads and propagation settings has been conducted by means of the official NDN simulator, *ndnSIM*. Our evaluation results show that SIRC outperforms the vanilla NDN approach as well as the often proposed window-based timeout-driven Additive Increase Multiplicative Decrease (AIMD) solutions in wired networks.**

***Index Terms*—Named Data Networking, Transport, Wireless Ad Hoc Network, ndnSIM, Interest rate control**

I. INTRODUCTION

Information-Centric Networking (ICN) has become one of the main topics of the Future Internet research, with several projects in active development worldwide [1]. In this arena, the Named Data Networking (NDN) architecture [2] has rapidly gained consensus, thanks to the simple, robust and effective communication model, advocated in the Content-Centric Networking (CCN) proposal [3], which founds on hierarchical, location-independent *content names*. In NDN, information delivery is driven by the data consumer, which uses *Interest* packets to request content *by name*. The content source, or any other network node that temporarily stores the requested content, responds to an Interest with a *Data* packet that contains pieces (chunks) of the named content and additional information for authentication and data-integrity.

A transport strategy in a content-centric network has to control Interests transmissions to effect Data delivery, according to the available resources and network dynamics. In this paper, we focus on named data transport control for wireless ad hoc environments so as to provide reliable data delivery by *retransmitting Interests* in case of missing Data packets; and to optimise between performance and network capacity utilization, through *control of the Interest pipeline* at the receiver side.

A few recent studies have investigated NDN in wireless networks mainly with focus on forwarding strategies [4]–[7], while less effort has been invested to analyze transport mechanisms [5]. On the other hand, until now, the topic of transport solutions has received substantial attention in the infrastructured wired domain with numerous proposals advocating TCP-variant approaches adapted for receiver-driven control, mainly based on AIMD (Additive Increase Multiplicative Decrease) mechanisms controlled by timeouts [8], [9], [11]–[14].

However, one important differentiating factor from today's end-to-end TCP, which affects invariably the performance of these proposals, is the fact that communication in NDN can dynamically vary from *one-to-one* to *one-to-many* nodes, due to content multi-homing at various caching points [9]. The impact of multi-homed content is further exacerbated in a wireless ad hoc environment due to nodes mobility: closer content stores may start serving suddenly the consumer, while other content stores could become suddenly unreachable.

Finally, the typical TCP control-loop, which reacts invariably to packet losses irrespective of their cause (collisions, errors, congestion, channel variations), is subject to an additional source of variability in wireless environments. Channel impairments and node mobility can cause frequent packet losses such that AIMD approaches, that depend on timeouts, do not scale/stabilise due to the coarse grained reactions: the Interest pipeline climbs up slowly in response to the Data, but backs off drastically in response to a non-stabilising temporal estimate of the Bandwidth-Delay Product (BDP).

For these reasons, in this work we have pursued a different approach for the NDN transport and proposed a strategy that tries to: *(i)* react in more fine grained steps and more conservatively to sudden Round Trip Time (RTT) fluctuations, *(ii)* adapt the Interest retransmission policy in face of content multi-homing. The contributions of the paper can be summarized as follows:

1. We propose an *Interest retransmission scheme* based on the computation of an Interest Retransmission Timeout (RTO) that recovers packet losses and counteracts fluctuations due to multi-homed content.

2. We address flow-control and congestion control through a *Self-regulating Interest Rate Control* (SIRC) scheme that relies on inter-arrivals times of Data packets to regulate the Interest sending rate and pace at the receiver side. SIRC is a more robust feedback mechanism for adaptation than timeout-based AIMD schemes, since it does not respond discreetly and spasmodically to timeouts, as most AIMD proposed solutions, but rather follows in a continuous manner the more smoothly

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varying Data inter-arrivals.

The proposed solution has been implemented in the official NDN simulator, *ndnSIM* [10]. Evaluation has been conducted to study the impact of multi-homed content over the Interest retransmission policy and to compare the performance of the proposed scheme against *(i)* "one Interest per RTT", typically used in vanilla NDN implementations, and *(ii)* a timeout controlled AIMD strategy, as representative of several proposals for transport control in wired NDN networks [8], [9]. The rest of the paper is organized as follows. Section II introduces NDN transport issues and related work. Section III presents our transport layer proposal. Section IV and V report simulation settings and results, respectively. Section VI provides conclusion and hints for future work.

II. NDN Transport Schemes

A. Wired domain

Currently, most of the work in relation to transport strategies and flow-control for NDN is focused on (or at least tested in) wired topologies. The main reason is that the wired environment is easier to tackle until some robust solutions have emerged and matured. The vast majority of proposals so far consider an AIMD controlled Interest pipeline based on timeouts (which in turn are estimators from RTT measurements). In [11] the authors employ a timeout estimator straight-forwardly analogous to the one of TCP (which is a function of an exponentially weighted moving average of the smoothed RTT). In [8], [12] the timeout estimator has been improved to be itself an exponential weighted average process over its history in time (in hope to stabilise it in face of the unpredictably varying BDP, in NDN). In [13], [14] the authors follow two technically different but semantically analogous approaches for conducting an independent RTT measurement and BDP estimation per content diffusion point that the receiver "tracks". Thereby either the timeout estimation is discreetly re-adapted to the BDP of each content store [14], or a separate AIMD window of Interests is used for each content store [13]. Both approaches seem to attain better stability and closer matching of the available capacity at the expense of either additional state or Interest re-ordering.

Overall, however, in all the aforementioned approaches what comes out as a lesson is that using timeouts for an AIMD controlled Interest pipeline has serious stability, performance and cost issues in face of the frequent BDP variations due to content multi-homing. By contrast, network-side metrics as in [15] that exploit different measures than RTT samples, namely *inter-arrival times of Interest/Data packets*, tend to be more promising in smoothing the flow of traffic and stabilising it close enough to network's maximum utility. The question would be how well do these solutions perform also in the error-prone wireless channel. In fact, the herein proposed solution partly alludes to this question as we have used a similar heuristic (packet inter-arrivals) but this time with the control logic sitting at the NDN consumer, rather than the network side.

B. Wireless ad hoc domain

Transport strategies that use AIMD control of Interest transmissions and temporal estimators are haunted by efficiency and stability issues when data are located at different places in the network [9]. Such problems can be a lot more challenging to address in (multi-hop) wireless environments, where the RTT measurement is much more unreliable due to errors, channel rate variability and node mobility. As discussed so far, the focus of this work has been therefore to identify and effectively exploit a measurement other than the RTT, for controlling the Interest pipeline. This measurement should lead to the development of a metric that is more robust to fast BDP variations, tolerant to timeouts due to conditions other than congestion and thereby more suitable for the wireless setting.

A first proposed Interest flow-control scheme for wireless ad hoc networks is E-CHANET [5]. It is devised for broadcast communications over IEEE 802.11 networks, and regulates the Interest transmission rate on the basis of both local information (on the status of congestion in a node on the path) and global information (on the status of congestion in the network). Specifically, two main factors are considered in the Interest transmission rate computation: *(i)* explicit feedback about the sustainable packet transmission rate (STR) computed by each node in the network; *(ii)* the actual Data arrival rate, measured at the consumer on the reception of each requested Data. However, one of the critical issue in the E-CHANET design is the need for each node to make a reliable estimation of the STR by monitoring the status of its queues. This information is required to be transmitted in every Data by using an additional packet's field.

In this paper, we rely on the E-CHANET proposal [5] but make a step forward by considering a fully self-regulating scheme that does not use STR feedback. Instead, it relies simply on Data inter-arrival times. The suitability of Data inter-arrivals as a metric is also affirmed (in the context of wired networks) in [15], while the possible effects for receivers have also been briefly discussed in [9]. We also present a comprehensive analysis of the effects multi-homed content can produce over temporal estimators (RTTs/RTOs) and we show how our proposed retransmission scheme can mitigate them.

III. A Transport Strategy for Wireless NDN

In this section we present a novel transport mechanism that is compliant with the reference NDN architecture (unlike other proposals, we do not advocate architectural changes), and addresses the challenges of wireless ad-hoc environments. The proposed *Self-regulating Interest Rate Control* (SIRC) scheme is responsible for scheduling Interest transmission and retransmissions; specifically:

- the Interest transmission is continuously adapted according to the inter-arrivals of Data packets that are monitored at the consumer side and used as an indirect estimation of the available network bandwidth;
- Interest retransmissions are triggered according to the expiration of a timer maintained at the consumer side,

whose setting borrows some TCP tenets, albeit adjusted to account for the effects of content multi-homing.

A. Retransmission timeout and content multi-homing

Currently, several NDN implementations (including ndnSIM) are based on TCP's algorithm for retransmission timeout estimation. Likewise, albeit with a slightly modified policy, we assume that RTO is set on a per Interest basis and depends on the RTT parameter, which is smoothed according to an exponential weighted moving average, as follows:

$$\overline{RTT_{new}} = (1-\alpha)\overline{RTT_{old}} + \alpha RTT_m \quad (1)$$

where $\overline{RTT_{old}}$ is the RTT estimate at the previous step, RTT_m is the round trip time measurement from the most recently received Data, and α is set in [0:1] and used to smooth the measured RTT. The consumer maintains information about the time instant that each Interest is sent and measures the RTT when the correspondent Data is received. After a fresh $\overline{RTT_{new}}$ estimation, the RTO is updated as follows:

$$RTO_{new} = \overline{RTT_{new}} + 4\sigma^2_{new} \quad (2)$$

with the variance σ^2_{new} computed by:

$$\sigma^2_{new} = (1-\beta)\sigma^2_{old} + \beta(|RTT_m - \overline{RTT_{old}}|) \quad (3)$$

where β is a smoothing factor in [0:1]. The $\overline{RTT}$ estimate (and related RTO) is not updated when the Data is received after an Interest retransmission to avoid ambiguity, as the consumer cannot distinguish if the incoming Data is related to the original Interest or its subsequent retransmission. Moreover, missing Data can be retransmitted locally by intermediate nodes that maintain a cached copy (instead of the provider), with a shorter retrieval delay.

In the more general case, Data may be retrieved from different locations and/or the consumer may change its data source during a content transfer because a better performing provider is detected or the current one becomes unavailable (e.g., due to mobility, energy run out, sleep mode). This phenomenon, that we call *provider switching*, can cause high *RTT fluctuations*. Two main adverse effects may follow a provider switch: *(i)* If a nearer provider is discovered, the computed RTT will be reduced compared to the previous values and the variance will increase with a consequent higher RTO; *(ii)* If the current provider becomes unreachable and a farther away provider answers the Interest, it is highly likely that the new RTT will increase from the previous values. If the new RTT is even higher than the current RTO, an Interest will be retransmitted before the Data arrive and while they are actually in flight. As a consequence, on Data reception, the RTT/RTO parameters will not be updated. This condition in which RTT/RTO are *frozen* to the old values can affect the subsequent Interests, unless a specific mechanism alerts the consumer about the provider switching.

In order to avoid the *RTT/RTO fluctuations and freezing* due to content multi-homing, one possible solution is to make the consumer aware about the provider (or cache) identifier (ID) so that it can recognize if the content source has changed and update the temporal estimators accordingly. The use of cache ID has been considered in the wired domain [9] as a means to compute more accurate estimators. To keep track of the provider ID in our wireless scenario, we decided to extract this information from the NDN forwarding plane that is provider-aware in our scenario. We use the routing information provided by the Listen First Broadcast Later (LFBL) [4] forwarding protocol, specifically designed for ad hoc networks, but any provider-aware forwarding strategy can be used to pass the provider ID information for transport purposes. We assume that, when a provider switching occurs, the consumer resets the RTT/RTO estimation and starts a new computation.

B. Self-regulating Interest Rate Control (SIRC)

The SIRC scheme adjusts the Interest transmission rate according to the so-called *Inter Data Gap* (IDG), which is computed by taking into account the arrival time of the N_{idg}-*th* most recently received Data packets, as in [5].

Let us consider a set of Data arrival events a_n at times t_n, where $n = 1, \ldots, N_{idg}$, a_1 is the most recent arrival and a_N is the oldest one. We refer to as $s_n = t_n - t_{n+1}$ the time elapsed between two Data arrival times. We also consider $s_0 = CurrentTime - t_1$ as the time interval between the instant in which the most recent Data arrives and the instant in which the estimation is performed. Value s_0 has to be ignored in calculating IDG unless it is large enough so that including it would increase the average [16].

The *Average Inter Data Gap*, $\overline{IDG}$, is computed by:

$$\overline{IDG} = max\left(\frac{1}{N_{idg}}\sum_{n=1}^{N_{idg}} s_n, \frac{1}{N_{idg}}\sum_{n=0}^{N_{idg}-1} s_n\right) \quad (4)$$

The *Interest rate control function* is a two-step process:

1. Init Mode. This is the starting phase used by the consumer to calculate the first estimation of the $\overline{IDG}$. It is based on slow start and AIMD mechanisms. Interest transmissions are associated with a variable congestion window referred to as *Interest Window* (IW): the consumer starts with the transmission of one Interest (IW=1) and increases its IW by one at each new received Data. This results in an exponential growth phase, so IW doubles at each RTT. Such behavior is maintained until a packet loss occurs, or the *Interest rate limit* of the network interface [17] is reached. If a packet loss is detected (the Interest RTO expires), the IW is halved and slow start begins again. Conversely, if the IW reaches the Interest rate limit, the consumer follows an AIMD scheme. When N_{idg} inter-data reception samples are collected and IDG can be computed, the consumer enters the *Normal Mode*.

2. Normal Mode. In this phase, the Interest transmission is determined according to the measured $\overline{IDG}$. When an application resumes after an *idle* period, the Interest rate control function goes back to the *Init Mode*.

In *Normal Mode*, a consumer transmits successive Interests spaced of a time interval called *Inter Interests GAP* (IIG), computed as follows:

$$IIG = min(f_s * \overline{IDG}, RTO) \quad (5)$$

where f_s is a speed factor whose value depends on the network dynamics, as explained in the following. Equation 5 ensures that the consumer can send at least an Interest at every RTO and forces an Interest transmission rate slightly higher than the received Data rate (i.e., creates a tendency for the transmission rate to increase). We can also observe that the IIG computation is inherently self-regulating w.r.t. the network conditions: in presence of congestion, in fact, the IDG becomes larger and the IIG increments as well. On the other hand, under light traffic load, the IDG shrinking directly leads to an IIG reduction.

We assume that $\frac{\overline{IDG}}{2} \leq IIG < \overline{IDG}$, therefore the factor f_s can be set in the range $[0.5; 0.9]$. Specifically, at the initial IIG computation, we set $f_s = 0.5$. Then, at every new IIG computation, f_s can be increased (or decreased) on the basis of the new IDG value as in Algorithm 1.

Algorithm 1 Speed factor f_s update

```
let f_s(new) ⇒ the new value of f_s
let f_s(old) ⇒ the past value of f_s
let f_{s,max} ⇒ the maximum value of f_s
let f_{s,min} ⇒ the minimum value of f_s
let f_{s,step} ⇒ the f_s increasing/decreasing step
let Error_{IDG} ⇒ (IDG_new − IDG_old) / IDG_new
let T_Error ⇒ the Error tolerance threshold
if (Error_{IDG} < −T_Error) and (f_s(old) > f_{s,min}) then
    f_s(new) ← f_s(old) − f_{s,step}
else if (Error_{IDG} > +T_Error) and (f_s(old) < f_{s,max}) then
    f_s(new) ← f_s(old) + f_{s,step}
end if
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If $Error_{\overline{IDG}}$ is positive and greater than the threshold T_{Error}, it means that the Data arrival rate is heavily decreasing and therefore it is appropriate to increment f_s in order to reduce the Interest transmission rate. Vice versa, if $Error_{\overline{IDG}}$ is negative and smaller than the threshold T_{Error}, it means that the Data arrival rate is strongly increasing and f_s can be reduced to increase the Interest transmission rate.

In case of provider switching, the consumer should take proper countermeasures to avoid detrimental fluctuations of the IIG estimate; so when a new provider detection is notified by LFBL, the consumer falls back to the *Init Mode* until N_{idg} samples are collected for $\overline{IDG}$ computation from the new provider.

IV. Simulation Setting

To evaluate the performance of the proposed NDN transport scheme, we use the open-source ndnSIM [10] module for ns-3. As a simulation scenario, we consider the lattice topology in Fig. 1, with 16 IEEE 802.11g-equipped nodes. The coverage range of each node is about 100 m, and the distance between two adjacent nodes is 70 m. Therefore, the maximum number of links that every node can establish with its neighbours is eight, with the exception of the nodes at the border that can communicate with 3 or 5 neighbours. Unless differently stated in the text, we assume that the node at the right upper extreme of the grid is the unique content provider, while the number of consumers, which are located at the bottom of the topology, ranges from 1 to 4. Each consumer requests a different content, split into 500 Data packets; this means that each consumer must transmit at least 500 Interests (plus retransmissions if the RTO expires). We extended ndnSIM to implement the proposed SIRC strategy and some simple, but highly representative, benchmarking transport schemes for comparison. These schemes deploy the same interest retransmission mechanism described in Section III.A, but exhibit different Interest rate regulation strategies:

- *No Pipelining (NoP).* The consumer issues a new Interest when the former one has been fulfilled or expired. This simple reference scheme allows at most *one Interest per RTT*.
- *AIMD.* The consumer follows a window-based flow control, which halves the IW when the RTO expires.

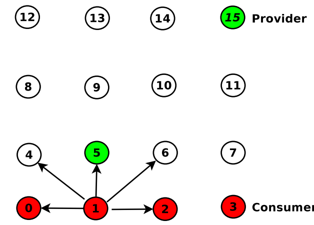


Fig. 1. Simulation scenario: 4x4 grid with a single provider.

TABLE I
SIMULATION SETTINGS

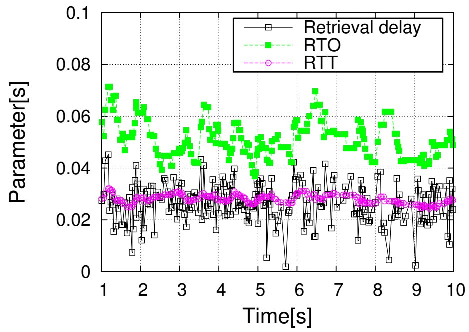
	Protocol	Setting(s)
Application	Content Size	500 Data packets
	Data Payload	1040 byte
NDN	Forwarding	LBFL
	Transport	NoP, AIMD, SIRC
		α=0.125, β=0.25
		N_{idg}=10
		$f_{s,max}$=0.9, $f_{s,min}$=0.5
		$f_{s,step}$=0.05, T_{Error}=0.5
Access	Technology	IEEE 802.11g

We perform simulation tests with the *Friis* radio propagation model and the *Rayleigh* model. The Friis model is selected to represent good channel conditions; in such a case, packet losses are mainly due to collisions of concurrent transmissions. By contrast, under Rayleigh propagation, packet reception is affected by fading and the error rate is higher.

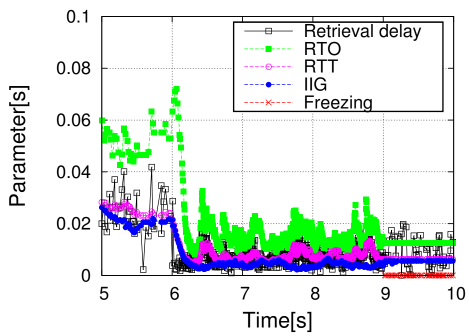
Simulation results are averaged over 15 independent runs and reported with the 95% confidence interval. The main simulation settings are summarized in Table I.

V. Results

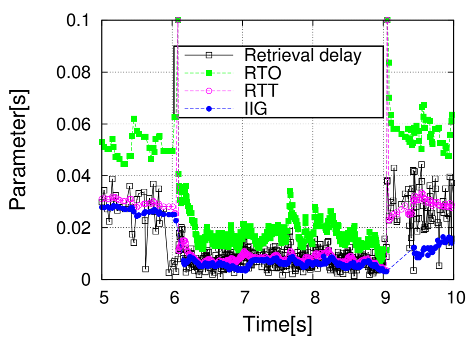
Two sets of results are presented and discussed. The first set aims to assert the reliability of the proposed new RTO



(a) Single provider scenario



(b) Provider switching without RTT/RTO reset (similar to TCP, and proposals in [8], [11]–[14])



(c) Provider switching with RTT/RTO reset

Fig. 2. In (a) single provider at node 15: RTT/RTO estimates are not updated in case of retransmissions. In (b) and (c) at time 6s node 5 is added as an additional provider and it then becomes unavailable again at instant 9s. In (b) RTT/RTO fluctuations and freezing are experienced when estimates are not reset.

estimator when the content is available at a single point and in presence of content multi-homing (Fig. 2). We also highlight the potential weaknesses arising if the plain TCP's RTO estimation (without provider awareness) is used and show how the proposed modifications address them. The second set of results focuses on the Interest rate regulation and compares NoP, AIMD and SIRC strategies (Fig. 3).

A. Interest retransmission results

Fig. 2 shows results with the proposed SIRC scheme only, and considers Friis propagation to illustrate more clearly the dynamics of the transport parameters. Data retrieval time, RTO, RTT and IIG parameters are plotted against the simulation time. We consider 4 active consumers; node 0 is the focused node for which the statistics are computed.

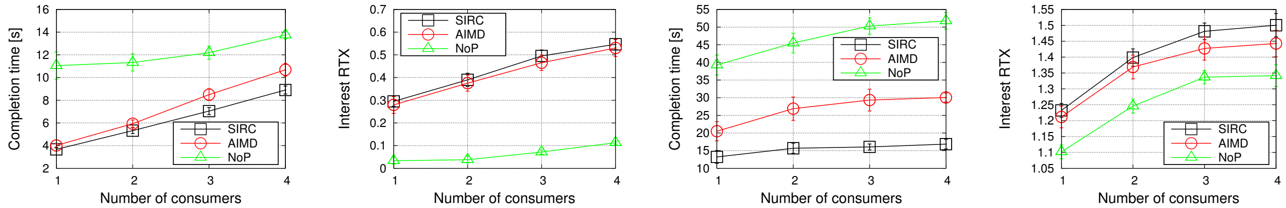
Impact of caching. As shown in Fig. 2(a), in presence of a single provider (node 15), the RTO estimation defined in TCP's algorithm seems reliable enough. Since caching is enabled at intermediate nodes, Data packets can be retrieved without recurring to the original provider in case of losses. When this happens, the retrieval delay significantly reduced ($< 0.01s$). RTO and RTT estimations are reasonably smooth without extreme variations and high-frequency fluctuations since they are not updated when a Data packet is received after a retransmission. When there is a loss, RTT and RTO remain at the previous value. It can be also observed that the RTT keeps an average over the single Data retrieval delay, with a value of about $0.03s$.

Provider switching-induced phenomena. In order to evaluate the effect of provider switching, we consider two providers in the grid: one is 3-hop away from the consumer (node 15) and the other one is 1-hop away (node 5), and the switching between them occurs during the content retrieval (Fig. 2(b) and 2(c)).

At the beginning node 15 is the only available provider selected by LFBL. Node 5 becomes available at time instant 6s. Once node 5 is detected by LFBL at a shorter distance, it is selected as the new provider. In Fig. 2(b) it can be observed that the *provider switching* event causes a strong and lasting RTO fluctuation of the plain TCP's RTO estimation. Indeed, due to the variance component, it becomes uselessly higher than needed regardless a provider at a shorter distance has been detected. The RTO takes some rounds to drop and settle close to the RTT values (about $0.01s$) for the BDP to the new provider, with a consequent slow-down of content retrieval operations. By enabling, instead, the RTO reset, as soon as the new provider is detected, the RTO estimator can better settle close to RTT values, as shown in Fig. 2(c). The spike at t=6 is due to the initial setting value ($0.1s$), but it is quickly recovered and efficiency in content retrieval is not heavily affected.

At time instant 9s, provider 5 becomes unavailable again and LBFL finds a new path towards the content by selecting again node 15 as a provider. An anomalous and more dangerous behaviour is exhibited in this case. Once an Interest is issued, the actual RTO estimate is not long enough to accommodate the required RTT towards the new provider that is farther away than the previous one. The consumer issues Interests that are not satisfied in time, and received (delayed) Data cannot be used for updating the RTT/RTO estimate, which therefore may be wrongly and indefinitely *frozen*, Fig. 2(b). Through the timeout reset, in Fig. 2(c), when the new provider is detected, the RTO can start to follow again the RTT measured at the consumer side and packet losses are significantly reduced.

The IIG update is also frozen when a provider switching event is detected. The consumer falls back to the *Init Mode* and collects new IDG samples required to reliably set the IIG parameter for subsequently issued Interest packets. As a general comment, IIG is always lower than RTT in Fig. 2(b) and 2(c). This is because more Interests can be transmitted per



(a) Friis. (b) Friis. (c) Rayleigh. (d) Rayleigh.

Fig. 3. Completion time (a), (c) and Interest retransmissions (b), (d) under *Friis* and *Rayleigh* channels, respectively, when varying the number of consumers.

RTT according to the rate of incoming Data packets.

B. Interest rate control results

The following metrics are computed to compare the performance of the three transport schemes: *(i) Completion time* is the time required to retrieve all the Data packets in the requested content; *(ii) Interest retransmissions* is the average number of Interests retransmitted by each consumer, normalized w.r.t. the expected number of Interests needed to retrieve the overall content.

Under the Friis propagation model in Fig. 3(a), the simple NoP scheme exhibits the longer completion time, more than doubled compared to the other solutions. The latter ones achieve a shorter completion at the expenses of a larger number of Interest retransmissions as witnessed in Fig. 3(b). As expected, this is especially true as the number of consumers increases due to the fact that Interests are issued more frequently and, consequently, more collisions are experienced. No substantial differences can be noticed between AIMD and SIRC, in the Friis propagation model, since a few packet losses are experienced which are only due to collisions. Things get completely different when considering an error-prone channel, where AIMD poorly behaves, because it drastically reduces the IW in case of a detected packet loss. As depicted in Fig. 3(c), SIRC significantly outperforms AIMD and better scales with the number of consumers, whereby it halves the completion time. On the other hand, the number of retransmitted Interests for SIRC in Fig. 3(d) is slightly higher than in AIMD because it reacts less drastically to losses.

VI. Discussions and Conclusion

In this paper we studied transport issues in named data wireless ad hoc networks. Specifically, we designed a solution encompassing the TCP's RTO estimation to trigger Interest retransmissions, but adapted to account for multi-homed content, and a novel self-regulating Interest rate control scheme for effective and robust flow-control, under high fluctuating network dynamics.

The reported results achieved through simulations in ndnSIM show the necessity of provider awareness to prevent the detrimental effects of *RTT/RTO fluctuations and freezing* in wireless environments. The proposed solution outperforms, in terms of efficiency and effective data retrieval, both the simple one Interest per RTT approach and other existing AIMD schemes based on timeout estimators, provided that channel errors highly affect packet exchange.

A deeper study is required for multi-homed contents by accounting for the fact that the location from which Data packets are retrieved may depend on a number of factors including caching policy and cache sizes, content popularity and forwarding routines. Overall it is worth noting that despite our driving focus on the wireless environment the SIRC logic has also an enabling potential in wired environments (albeit testing beyond the scope of this paper is required to establish and quantify this position).

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