Queue Arrival Characteristics of Catenated Rainfall Cells over Wireless Radio Links

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***Abstract*—The arrival of rain cells during rain events is an important factor applied in the deployment of site diversity for mitigating rainfall attenuation in communication systems. In this study, the queue arrival characteristics of rain cells over radio links are explored from ground measurements in Durban (29°52′S, 30°58′E) in South Africa and Butare (2°36′S, 29°44′E) in Rwanda. The results suggest that cumulative arrivals of rain cell queues influence the event duration and equivalent rain cell distance, during typical rain events.**

***Index Terms*—Rainfall queues, Semi-Markovian traffic, rain cells, Arrival distribution, radio links**

I. Introduction

With more emphasis being made on high speed communication networks, major players in the telecommunication industry are now employing higher bandwidths available in the microwave and millimeter wave spectrum. Unfortunately, this decision is highly dependent on the influence of rainfall, a phenomenon responsible for intense network outage and instabilities. Because local rainfall creates a bounded region of inhomogeneous medium (or rain cell) which affects the beam characteristics of antenna transmission and reception, there is larger interest in rain cell studies [1]. From space borne radars, rain cells may appear as elliptical or circular clouds, which follow each other sequentially [2]. When ground instruments are used for rain cell detection, they appear as truncated spikes joined together [3]. In both cases, rain cells can be considered as catenated cloud systems which travel over wireless links (in terrestrial systems) or act as stratified attenuation layers (in satellite-earth systems).

In [3], [4], several inferences were drawn from ground measurements using queue traffic analysis — confirming that rain cells appear as time series spikes exhibiting specific traffic patterns — which denotes a First Come, First Served (FCFS) semi-Markovian ($M/E_k/s$) queue. In other words, these catenated rain spikes have an exponentially-distributed arrivals and Erlang-distributed lifetimes (or service time). Since the distribution of rain cell arrivals is already known as given in [3], [4], it is pertinent to note that such cell lifetimes are often truncated. From the first cell arrival in the queue, a pattern of incomplete cell lifetime is always evident, because consequent cell arrivals tend to arrive earlier thereby denying preceding cells the opportunity to complete their lifecycles. This phenomenon results in queue service instability as explained in previous studies [4]. However, the overall duration of the rain event is expected to be highly dependent on the number of cell arrivals.

Therefore, this study will investigate on the nature of queue arrival of rain cells and their contributions to the eventual rain event duration and equivalent rain cell distance over radio links. Measurement for this work is carried out at two African sites of distinct climate: Durban (subtropical) and Butare (Equatorial).

TABLE I. Summary of Measurement Sites

LOCATION	COORDINATES	TOTAL RAINFALL (mm)	NUMBER OF EVENTS	CLIMATE
Durban, South Africa	29°52′S, 30°58′E	703.40	50	Subtropical
Butare, Rwanda	2°36′S, 29°44′E	561.43	51	Equatorial

II. Measurement and Data Processing

Measurements undertaken in this study were obtained at the University of KwaZulu-Natal, Durban and the National University of Rwanda, Butare. Time series data from these two sites measurement have periods as thus: Durban (between October 2008 and December 2010) and Butare (Between May 2012 and September 2012). In Table I, a summary of the nature of the measurement sites are presented. Previous queue parameters obtained in [3], [4] will also be employed for the purpose of simulation and comparison with actual measurements.

III. Results and Discussion

A. Queue Arrival Parameters at Measurement Sites

Queue parameters from the measurement sites consisting of service rate, arrival rate and overlap rate are obtained in [3], [4]. For this study, only the arrival rate parameter (λ_a) for these sites is applied as presented in Table II. Figure 1 shows a demonstration of the arrival rate parameters for the two sites. From this realization, it is seen that exponential arrivals have varied inter-arrival times, implying random traffic distribution.

B. Comparison of Simulated Queue Arrivals and Measurements

Since the lifetime of a cell is truncated by another arriving cell, the arrival distribution can be conveniently applied to model this scenario. Figure 2 shows the relationship between the total number of arrived spikes and the resulting rain event

TABLE II. Summary of Queue Arrival Parameters at Sites

LOCATION	ARRIVAL RATE PARAMETERS	
	$\lambda_a\ (min)^{-1}$	t_a(min)
Durban [3], [4]	0.1425	7.0169
Butare [3], [4]	0.1476	6.7754

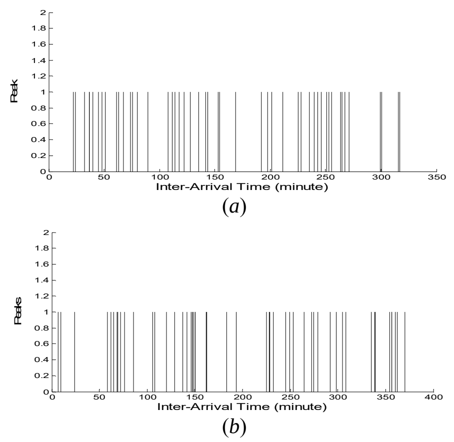

Figure 1. Demonstration of exponentially-distributed arrivals of rain cells (50 arrivals) (*a*) Durban (*b*) Butare

duration in typical rain events. A positive linear relationship is found to exist at both sites implying a strong correlation. This is verified by the results of the simulated queues which validate the behaviour of the measurement.

C. Relationship between Cells Arrivals and Rain Cell Sizes

The Equivalent Rain Cell Distance (ERCD) describes the total linear span (or distance) covered by the shadowy effect of the rain cell on the ground. In other works, this distance could represent the equivalent diameter for circular rain cells or equivalent major (or minor axis) for elliptical rain cells [1]. Mathematically, ECRD is the sum of random arrivals of individual rain cell distances. The Rain Cell Distance (RCD) is derived by multiplying truncated individual cell lifetimes by the cell translation speed, also known as the *advection velocity*. This velocity is determined by employing the rain rate boundary for stratiform/convective events in [5] and advection velocities in [6]. Thus, the expression for ERCD and RCD is given by,

$$RCD = 0.06vT \qquad [km] \qquad (1a)$$

and,

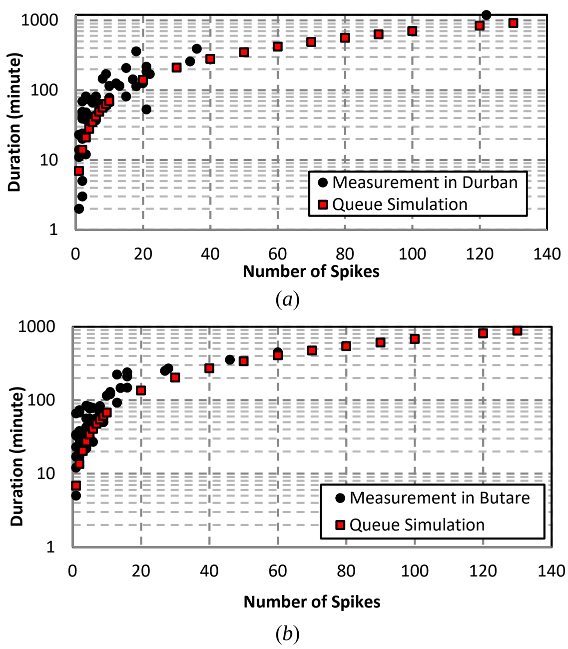

Figure 2. Relationship between number of spikes and duration of different rainfall events from measurement and simulation (*a*) Durban (*b*) Butare

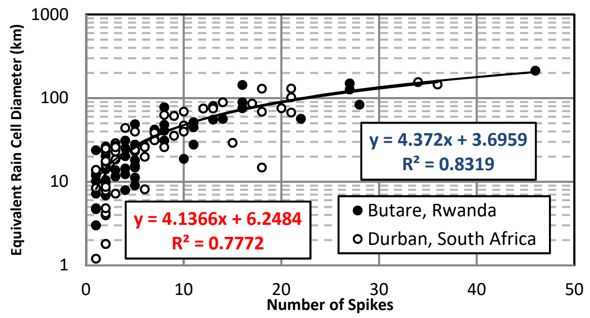

Figure 3. Relationship between number of spikes and equivalent rain cell distance for different rainfall events.

$$ERCD = \sum_i RCD_i \qquad [km] \qquad (1b)$$

where v is known as the advection velocity in m/s and T is the duration or individual cell lifetime in minute.

Figure 3 presents a plot of the number of spikes versus the ERCDs for different rain events at the two sites. The plot reveals similarities in the overall behaviour of rain cell arrivals in Durban and Butare. Other similarities related to rainfall microstructures between these two sites were similarly established in [4], [6]. This suggests a linear relationship exists between these two parameters as seen in the plot for Durban (in red marker) and Butare (in blue marker). Thus, our linear relationships are:

$$ERCD_{Butare} = 4.372n + 3.6959 \quad [km] \qquad (2a)$$
$$ERCD_{Durban} = 4.1366n + 6.2484 \quad [km] \qquad (2b)$$

where *n* is the total number of spikes per event.

IV. CONCLUSION

This study has demonstrated that queue arrivals of spikes are related to the event duration and the equivalent rain cell distance. This study will assist link designers to make informed decisions. This is applicable in the implementation of site diversity systems for terrestrial radio links and the development of adaptive mitigation techniques for satellite-earth communication systems.

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